TECHNIC of

ELECTROTHERAPY

and ITS PHYSICAL *and* PHYSIOLOGICAL BASIS

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SECOND PRINTING

By

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PREFACE

This text is published in response to requests from students to put in book form the material presented to them in their course of electrotherapy. The subject matter is essentially that which has been taught for the past sixteen years to classes for physicians, medical students, and technicians at Northwestern University Medical School.

This text is intended to provide a sound physical and physiological rationale for the technic and application of electrotherapy and not to replace the clinical textbooks now available. It is the hope of the authors that this book will be used to supplement those texts which emphasize the clinical aspect of electrotherapy.

The subject matter is divided into four parts:

A. *The effects and technical application of direct current*, in two sections: (1) deals with the fundamental principles and is presented in the form of laboratory experiments which may be performed by the students or demonstrated by the instructor; (2) presents the technic of application.

B. *Electrical muscle stimulation*, in three sections: (1) deals with the underlying principles of electrophysiology; (2) discusses the various types of apparatus in use; (3) teaches the technical application of the various currents studied and presents for the first time a technic for the stimulation of the vocal cords.

C. *Radiation*, in three sections: (1) fundamental physics; (2) physics and technic of application of thermogenic, or heat producing, radiation; (3) physics and technic of application of ultraviolet radiation.

D. *High frequency currents*, in six sections; (1) alternating current circuit theory; (2) high frequency current theory; (3) technic of local application of high frequency currents and fields; (4) effects of high frequency fields; (5) artificial fever and its technic of application; (6) physiology of artificial fever.

Throughout the book an attempt has been made to clarify the existing and somewhat confused nomenclature of electrotherapy We have suggested, for example, the use of the term *direct current* in place of galvanism, the term *tetanizing current* in place of faradic current, and *thermogenic radiation* in place of deep therapy

Instructive elementary laboratory experiments, requiring a minimum of simple apparatus, are given for the students to perform The importance of a written prescription for electrotherapy is stressed, and a sample prescription is given with each application discussed

The work has been written with two distinct groups of students in mind first, those students who are well grounded in science and who desire a thorough and comprehensive training in the fundamentals of electrotherapy, for whom the more advanced work in physics and mathematics appears in the form of footnotes, second, those students whose training in science is limited and hence who might find the subject matter in the footnotes difficult to follow For the latter group of students the technical material in the footnotes may be eliminated without in any way interfering with the clarity or continuity of the text

We have attempted to replace empiricism with rationalization It is our conviction, based on our teaching experience over the past twenty years, that rationalization is the best pedagogic method and is the only sound basis for progress in the field of physical medicine Even though certain theories presented in the text may need to be modified as the result of the discovery of new facts in the next few years, the history of science shows that theoretical rationalization, right or wrong, serves to stimulate progress

Physical medicine—of which electrotherapy is an important part—is an accepted field in medicine, and as such it should be presented scientifically so that it be accorded the recognition which it merits Physical medicine, as its name implies, is the diagnostic and therapeutic application of physical agencies Physics, chemistry, physiology, and anatomy—all are involved in the study and application of physical medicine Hence, the scientific prep

aration of the men in this field should be as thorough and comprehensive as that of men in any other field of medicine.

Therefore, we have attempted to present the subject matter of this book in a manner which we hope will aid to establish the scientific viewpoint, which we believe is so necessary for the rational development of electrotherapy.

We wish to express our thanks to those who have given us valuable suggestions regarding the preparation of this book.

May 1, 1944 S. L. Osborne
Chicago, Illinois H J. Holmquest

FOREWORD

PUBLICATION of this book could hardly have been more timely had it been possible for the authors, years ago, to predetermine the exact moment at which progress in their research and study would justify a comprehensive text Here is a scholarly discussion of the basic physics and physiology of electrotherapy, combined with a clear outline of the proper technique of application It is a source book on the *how* and *why*, as well as the *what*, of a branch of medical science brought into greater prominence by wartime problems

After World War I, electrotherapy received great impetus in the field of rehabilitation There came a period of great expansion both in the design and manufacture and in the use of electrotherapeutic apparatus Unfortunately, there was also an expansion in claims—many of which were not supported by adequate evidence Logically, then, at the annual meeting of the American Medical Association in May, 1925, Dr Joseph F Smith of Wisconsin, who realized with many others of the profession the potentialities of scientific physical medicine brought a resolution before the House of Delegates urging the Board of Trustees to establish a Council on Physical Medicine The resolution was adopted and the Board of Trustees, at the meeting the following September, created the Council It consisted originally of nine men selected from the ranks of chemists, physicists pathologists physiologists, radiologists, and clinicians Later the membership was increased to twelve Since its establishment, the Council has exerted a tremendous influence in furthering the development of effective apparatus and in encouraging its intelligent use by the profession

The field of rehabilitation consequent to World War II indicates ever greater need for the rational application of electrotherapeutics, and this, in turn, emphasizes the necessity for specially trained personnel—physicians to prescribe and technicians to perform

In the words of Dr. Eben J. Carey, Marquette University School of Medicine, "The present national emergency is a challenge to each of us to see that physical therapy is no longer neglected in our medical curriculum for undergraduate medical students"

Increasing numbers of medical schools are including in the undergraduate curriculum a required course in physical medicine In addition to such a course, students at Northwestern University Medical School are given instruction in the physiologic effects of electricity and other physical agents as a part of their courses in physiology. Furthermore, this institution, recognizing the importance of sound training in physical medicine, long ago instituted courses of study leading to graduate degrees for properly qualified students.

For all such courses, this book will serve as an excellent text. And of equal importance is its value to the practicing physician and to the technician as a reference work as well as a guide to the correct administration of physical therapy.

Dr. Osborne has for many years been engaged not only in the clinical application of electrotherapy, but also in research to determine its rationale. He has published numerous papers on the clinical uses of electrotherapy and its basic physiologic effects For the past ten years he has worked with Dr. A. C. Ivy, Chairman and Professor of the Physiology Department of Northwestern University Medical School, in this field In addition to his clinical and basic research in electrotherapy, Dr. Osborne is actively engaged in teaching undergraduate students, technicians, and graduate students.

Mr. Holmquest was for several years an instructor in physics and electrical engineering at Lewis Institute, Chicago In teaching physics to pre-medical students at this institution, he came to appreciate the necessity of so presenting physical knowledge that pre-medical students would realize its importance as a fundamental to their chosen profession Subsequently, he became the executive secretary of the Council on Physical Medicine of the American Medical Association, which position he held from the time of its establishment in 1926 until 1930 Here he had ample

opportunity to examine the physical claims made for electrotherapy apparatus, and to supervise the evaluation of the clinical results obtainable with such devices. It was during this period that Mr. Holmquest became associated with Northwestern University Medical School in the capacity of lecturer in applied physics in the Department of Physical Medicine. In addition to lecturing on the physical aspects of electrotherapy, he is called upon by several departments of the medical school as a consultant physicist and engineer in various research problems. Since 1930, Mr. Holmquest has been a research engineer for the General Electric X-Ray Corporation.

It is the combination of physiologist thoroughly trained in physical therapy technique with physicist who has devoted himself to the study of medical physics that has made possible the production of such a book as this.

The authors realize that they cannot write "Finis" at the end of their present work. They are already planning new research, for they are in agreement that the study of this subject must continue indefinitely. It must be realized that both basic and clinical research are necessary to the continued advance of electrotherapy. In these pages are provided new points of departure for the carefully charted progress of the future, as well as the fund of useful knowledge essential to the practicing physician and the physical therapy technician's thorough understanding of the rationale of electrotherapy. It is indeed a book of fundamental worth.

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CONTENTS

PART A DIRECT CURRENT

SECTION ONE GENERAL CONSIDERATIONS

SECTION TWO TECHNIC OF APPLICATION

PART B MUSCLE STIMULATION BY ELECTRIC CURRENTS

SECTION ONE GENERAL CONSIDERATIONS

SECTION TWO TYPES OF APPARATUS IN USE

SECTION THREE TECHNIC OF APPLICATION

PART C RADIATION

SECTION ONE GENERAL CONSIDERATIONS

SECTION TWO THERMOGENIC RADIATION

SECTION THREE ULTRAVIOLET RADIATION

PART D HIGH FREQUENCY CURRENTS

SECTION ONE ELEMENTARY ALTERNATING CURRENT CIRCUIT THEORY

SECTION TWO ALTERNATING CURRENTS OF HIGH FREQUENCY

SECTION THREE TECHNIC OF LOCAL APPLICATION

SECTION FOUR EFFECTS OF HIGH FREQUENCY FIELDS

SECTION FIVE TECHNIC OF GENERAL APPLICATION (ARTIFICIAL FEVER)

SECTION SIX PHYSIOLOGY OF ARTIFICIAL FEVER BY PHYSICAL MEANS

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PART A DIRECT CURRENT

SECTION ONE GENERAL CONSIDERATIONS

I DEFINITION OF DIRECT CURRENT The flow of an electric current may be unidirectional or alternating A *Direct or Galvanic Current*, as employed in medicine, is a unidirectional continuous current The applications discussed in this section require that the current be constant in intensity Other terms used to designate this current in the field of medicine are continuous, constant, unidirectional, and such inaccurate, misleading terms as "current of low tension" In the interest of uniformity of nomenclature and accuracy of definition, it is highly desirable that the term *direct current* be adopted to conform with internationally accepted electrical nomenclature Hereafter in this discussion the term *direct current* shall be used to describe the current having the characteristics of the so-called galvanic current

The direct current, when passed through an electrolyte, presents positive and negative polarity effects The reactions found at the positive pole are different from those at the negative pole, in fact, they are diametrically opposed It is necessary, therefore, to consider the direct current as providing two distinct therapeutic agents:

1. Positive direct current.
2. Negative direct current.

II. Sources of the Direct Current.

A *Chemical*

1. Batteries
   a Wet cells
   b. "B" batteries

B. *Mechanical* Motor-generator set. A small motor is used to run a small generator which supplies current for the patient The

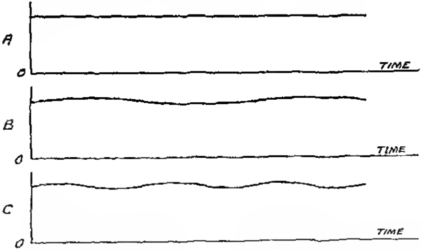


Fig 1 Schematic representation of the type of direct current obtained from various sources (*A*) battery, (*B*) electronic rectifier with filter, (*C*) motor generator

current is collected from a commutator and will, therefore, not be as "smooth" as a battery current It may, however, be made

practically ripple free by means of a suitable electrical filter

C *Electronic* An alternating current may be rectified by means of a rectifying tube, which converts it into a unidirectional current It is then made as "smooth" as possible by means of a suitable filter With an adequate filter, the resultant current will be for all practical purposes as smooth and ripple free as the current from a battery

III ESSENTIAL ELEMENTS OF A GENERATOR All satisfactory generators must be equipped with certain fundamental mechanisms or devices to insure their satisfactory clinical operation The following meters, switches, and controls must be provided

1 *A Milliammeter* This meter indicates the current in milliamperes received by the patient The meter should have two current ranges one a high scale—from 0 to at least 100 ma , and the other a low scale—from 0 to 20 ma or less, depending upon current range employed By means of a switch, either meter scale may be selected

2 *A Line Switch* to control the current flow from the house line to the machine

3 *A Polarity Switch* By use of this switch the polarity of the terminals, and consequently that of the electrodes, can be changed at will

4 *An Intensity Regulator* The regulator may be a potentiometer or an arrangement of resistances to control current flow to the patient When the intensity regulator is at zero, no current should be flowing in the patient circuit As the intensity regulator is moved in the direction of "increase," current flow in the patient circuit is increased Current intensity should never be increased or decreased abruptly

5 *Patient's Terminals* One terminal will be positive and the other negative The polarity switch indicates the polarity of the respective terminals

IV EXPERIMENTS The therapeutic application of positive or negative direct current is based on the effects produced by the

current The following experiments have been devised to teach the effects obtainable with the direct current These experiments should be conducted under the supervision of an instructor if

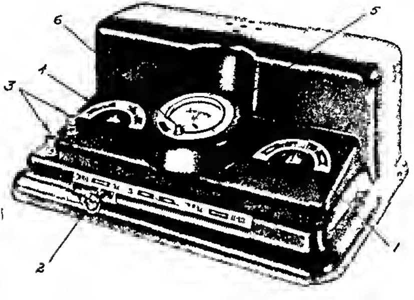


Fig 2 Modern direct current generator of the electronic rectifying type (1) line switch, (2) intensity regulator, (3) patient's terminals (4) polarity switch which permits the polarity of the electrodes to be reversed without disturbing the connections to them, (5) milliammeter to indicate current to patient having two current ranges 0 to 20 ma and 0 to 200 ma. with zero point at the center of the scale permitting deflection in either direction (6) switch for changing the current range of the milliammeter

possible, and the findings carefully recorded The knowledge which is obtained from these experiments will serve as a guide in the intelligent clinical application of positive and negative direct currents

Some generators of direct current are equipped with a volt meter For clinical application this is not essential but in these experiments a voltmeter is required for making certain measure ments Unless the generator used in these experiments is equipped with a voltmeter, a portable meter must be provided

EXPERIMENT I—WATER ELECTROLYSIS

Object:

To demonstrate the effects of direct current passing through water.

Theory:

An electric current can be conducted through water only when certain substances are in solution. These substances are spoken of as electrolytes or ionogens, since they yield ions, and water containing an electrolyte is called an electrolytic solution. Solutions of acids, bases, and salts are excellent conductors. The current is carried through the solution by means of the ions into which these electrolytes dissociate. These ions or particles are either positively or negatively charged according to whether they have lost or gained electrons in the process of dissociation. For example, in an acid solution such as that of sulphuric acid, a given number of the molecules dissociate into positive H ions and negative SO_4 ions, while the others remain combined as H_2SO_4. In this process, the neutral H atom loses one of its electrons and thus becomes a positive H ion. The neutral SO_4 atom gains two electrons and thus becomes a negatively charged SO_4 ion.

When an electric current is passed through such a solution, the positively charged ions move in the direction of the negative electrode, while the negatively charged ions move in the direction of the positive electrode. The movement conforms to the physical law that unlike charges attract and like charges repel.

When the H ion reaches the negative electrode, it gives up its charge and free hydrogen gas is liberated. When the SO_4 ion reaches the positive electrode, it gives up its charge and then recombines with the hydrogen of water to form H_2SO_4, releasing free oxygen gas as illustrated in Fig 3.

The reactions taking place can be represented by means of the following equation:

$$
\begin{array}{l}
2\,H_2SO_4 + 2\,H_2O + \text{direct current} \rightarrow \\
2\,H_2\uparrow \text{ at negative electrode and} \\
2\,H_2SO_4 + O_2\uparrow \text{ at positive electrode} \\
\rightleftharpoons
\end{array}
$$

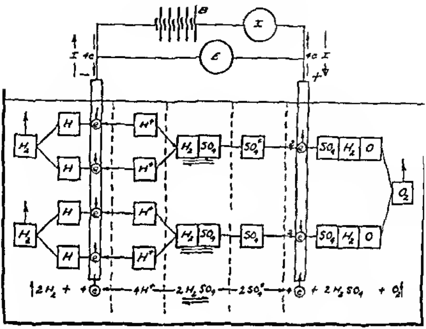


FIG 3 *Water Electrolysis* Dissociation of an electrolyte and the mechanism of current conduction in an electrolytic solution The sulphuric acid on going into solution, is dissociated into hydrogen (H) and sulphate radicle (SO_4) ions, each molecule of H_2SO_4 that is dissociated yielding one SO_4 ion and two H ions *On coming into contact with the negative and positive poles* the charges carried by these ions are neutralized and the chemically active atoms become free to escape as a gas, to precipitate, or to react with other atoms or radicles that might be present to form new compounds For each two molecules of H_2SO_4 that are dissociated, there will be two SO_4 ions and four H ions Each of the SO_4 ions carries a double charge and on coming into contact with the positive pole will give up two electronic charges—a total for the two SO_4 ions of four electronic charges Each of the four hydrogen ions carries a positive charge equal in magnitude to the charge on an electron *On coming in contact with the negative electrode*, each hydrogen ion will lose its positive charge or what amounts to the same thing will receive an electronic charge resulting in neutralization of the charge carried by the ion For the four hydrogen ions a total of four electronic charges will be received—a total charge equal to the total charge given up by the SO_4 ions at the opposite pole

In the figure the arrows with open heads indicate the direction of flow of the electronic current—that is the direction in which the negative charges of electricity flow If a battery B, an ammeter I and a voltmeter E are connected *as indicated in the figure*, a *current will flow and the magnitude* of this current will be *determined by the voltage impressed upon the electrodes* The current will apparently flow in the direction represented by the arrows with

Apparatus

1 Direct current generator with milliammeter
2 Direct current voltmeter, range 0 to 150 volts
3 One set of patient's conducting cords
4 One 250 cc glass beaker
5 Two metal foil strips, 3 × ½ inches, to serve as electrodes
6 Two electrode clips to fasten electrodes on beaker and to serve as terminals for conducting cords
7 Dilute sulphuric acid
8 Sugar (granulated)
9 Distilled water
10 Spatulas (wood)

Procedure

A *Distilled Water*

1 Place 200 cc distilled water in beaker
2 Cut one end of each metal foil electrode to a sharp point Place the electrodes in the solution, directly opposite to and equidistant from each other, along the inner surface of the beaker Fix electrodes to sides of beaker by bending ends over the edge of the beaker Clamp electrodes firmly to the beaker with the electrode clips
3 Attach patient's connecting cords leading from the generator to the electrode clips

---

closed heads which is opposite to the direction of electronic flow The magnitude of the current I is usually expressed in amperes or milliamperes and is equal to the number of coulombs or milli coulombs of electricity flowing through the circuit per second The charge on an electron which is the charge carried by the hydrogen ion or ½ that carried by the SO ion is 4 77 × 10^{-10} statcoulombs In abcoulombs the charge is 1 59 × 10^{-20}, and in coulombs *15 9 × 10^{-20} Therefore if the milliammeter indicates a current flow of 1 ma* or 001 ampere or 001 coulomb per second 001 ÷ 15 9 × 10^{-20} or 6 29 × 10^{15} electronic charges must be liberated at the positive electrode each second Since four charges are received for each two molecules of H_2SO_4 dissociated 3 145 × 10^{15} molecules of H_2SO_4 must be dissociated per second and a sufficiently high voltage must be impressed upon the electrodes to impart such a velocity to the ions that 3 145 × 10^{15} SO_4 ions will reach the positive electrode every second.

4. Connect voltmeter, if generator is not equipped with one, across electrodes.
5. Connect generator to the house supply and turn switch "on," first setting the meter on low reading scale (0 to 15 ma.) and the intensity regulator at zero. Gradually increase current intensity regulator setting until maximum obtainable current flow is secured.
6. Record in Table I the milliamperage and voltage shown on meters.

B *Distilled Water plus Sugar*

1. Without disturbing the set-up in "A", add a small amount of sugar, and stir until dissolved.
2. Read and record the milliamperage and the voltage.

C. *Distilled Water plus Sugar plus Sulphuric Acid.*

1. Make no change in the above set-up except to change milliammeter to the high reading scale (0 to 150 ma) Add to the solution a few cc. of dilute sulphuric acid and stir well.
2. Read and record the current and the voltage.

TABLE 1

Experiment	Ma	Volts	Resistance	Conductance
A Distilled Water	3	75		
B Distilled Water plus Sugar	3	75		
C Distilled Water plus Sugar plus H_2SO_4	40	5		

Numbers printed are approximate relative values that will be obtained.

Conclusions

1 The electrical conductivity of water is due solely to the presence of ions—which are electrically charged atoms into which substances known as electrolytes dissociate

2 There are certain substances, such as sugar, which dissolve in water but which do not dissociate into electrically charged ions Solutions of such substances will not conduct electricity Such substances are known as non electrolytes

Discussion

From experiments A, B, and C, it is quite evident that distilled water is practically a non-conductor of electricity It is quite evident also that the presence of a solute such as sugar does not render the solution conductive However, the addition of a few cc of H_2SO_4 renders the solution an excellent conductor of electricity The conductivity is due to the dissociation of H_2SO_4 molecules into ions of H^+ and SO_4 It should be kept in mind that these ions—electrically charged particles—are chemically inert, and become active only when they lose their charge or the charge is neutralized For every salt, acid, or base a given number of the molecules will dissociate—a number which is specific under given conditions for each particular substance The degree of acidity of an acid is dependent on the number of H ions in solution, the greater the number, the more acid the solution In any electrolytic solution, there is a continuous breaking apart of molecules to form ions and a recombining of the ions to form molecules ($H_2SO_4 \rightleftharpoons 2H^+ + SO_4$) The number of ions present in a solution is always constant for any particular electrolyte for a given temperature and concentration of the solution

The important physical law that unlike charges attract and *like charges repel, must be thoroughly understood and remembered* by the student because of its importance in the therapeutic application of the direct current

One of the most striking, and, from a therapeutic standpoint, one of the most important characteristics of the passage of a direct current through an electrolyte, is the absence of any chemical

action in the general bulk of the electrolyte as the result of the passage of the ions; it is only when the ions surrender their electrical charges or have them neutralized that they regain their chemical affinities and exercise their specific reactions

This experiment also demonstrates the manner in which electric current is carried through the tissues of the body. The tissue fluids contain a great variety of ions and these serve as conductors of the current just as the H and SO_4 ions did in this experiment.

EXPERIMENT 2—ATTRACTION OF IONS WITH LIBERATION OF ATOMS AT THE ELECTRODES

Object:

To demonstrate that ions on reaching their attracting electrodes lose their electric charge, become free atoms and are liberated, or in the presence of substances for which they have a chemical affinity, form new chemical combinations.

Theory:

The electric current is carried through a solution by means of ions Unlike charges attract. When the ions reach their attracting electrodes, they immediately lose their electric charge and become active atoms The atoms immediately combine with atoms of other substances which may be present to form new products, or in the absence of such substances, the atoms may either be deposited or liberated as gases.

Apparatus:

1. Direct current generator and conducting cords.
2. One extra large, wide-mouthed test tube.
3. Weak solution of starch to which a small amount of 5 per cent potassium iodide solution has been added
4. Two copper disk electrodes soldered to enamel-insulated copper wires as illustrated in Fig. 7.

Procedure:

1. Fill the large test tube with the starch and potassium iodide solution.
2. Place the two copper electrodes into the solution as illustrated in Fig. 7.
3. Connect the positive terminal of the generator to the upper electrode in the test tube and the negative terminal to the lower electrode.
4. Switch on the current and raise the current intensity to 30-60 ma.

Observations:

After a few minutes a brilliant blue stream is observed extending from the under surface of the upper copper disk electrode.

Conclusions:

The iodine ions are attracted to the positive electrode where the iodine loses its charge, becomes free iodine, and unites with the starch to give the typical starch-iodine reaction.

Discussion:

This experiment clearly demonstrates that an ion is chemically inert but as soon as its electric charge is lost chemical reactions take place. In this instance there was no evidence of the presence of the iodine in the solution until the current was passed through it. Because of the attraction of unlike charges the iodine ion was attracted to the positive electrode, where its charge was neutralized, liberating free atomic iodine which immediately combined with the starch.

In clinical application, the solution at the active electrode serves as an excellent medium for transporting the electric current into the tissues. However, once the drug comes into contact with the fluids of the tissues, other faster moving ions such as H^+, Cl^-, OH^-, and Na^+ are encountered. These ions will then conduct the current. The ions originally introduced, on losing their charge and becoming chemically active atoms, combine with the

tissue proteins to form soluble or insoluble compounds Therefore, there can be no great penetration of medicinal substances into tissues by the action of a direct current. The current serves merely to introduce these ions, and for this reason the term ION TRANSFER has been adopted in preference to the many incorrect and rather misleading terms formerly employed.

EXPERIMENT 3—ACID AND ALKALINE REACTIONS OF THE DIRECT CURRENT

Object:

To demonstrate the acid and alkaline reactions of the direct current.

Theory:

With the passage of an electric current through an electrolytic solution, the negatively charged ions flow toward the positive pole When the negative ions contact the positive pole, the electric charge of the ions is neutralized, and the free atoms can combine with hydrogen atoms of water. Thus, in Experiment 1 we found sulphuric acid (H_2SO_4) at the positive pole with the liberation of oxygen gas (O_2) The positively charged H ions are neutralized at the negative pole. The free atoms of hydrogen combine to form molecules of hydrogen gas (H_2), which is liberated. The end products found at the respective poles will vary according to the ions present in the solution; but, regardless of the electrolytic substance in solution, the positive pole will always show an acid reaction and the negative pole an alkaline reaction

Apparatus:

1. Direct current generator.
2. One set of conducting cords.
3. Small beaker of tap water.
4. Red and blue litmus paper.
5. White cardboard.
6. Two electrode clips.

7. Two wood spring clothesline clips.
8 Sandbag, thumb tacks, or other means of holding the cardboard on the table.

Procedure:

Place a piece of wet litmus paper along the edge of a sheet of white cardboard. Fasten the metal ends of the patient's conducting cords about 1 inch apart on the litmus paper by means of the clips. Fig. 4. Connect the other ends of the conducting cords to the direct current generator and switch on the current. Use approximately 5 ma. of current for a few minutes, or until the litmus paper shows a definite color change in the region of the metal ends of the conducting cords. Check the polarity of the conducting cords. Record observations.

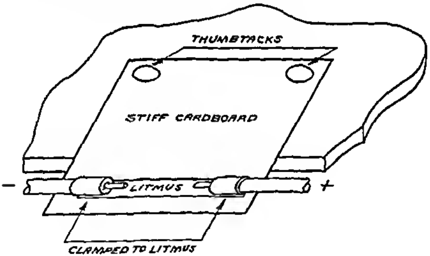


FIG 4 Arrangement of apparatus for Experiment 3

Observations:

TABLE 2

Polarity	Blue Litmus	Red Litmus
Positive	Red	No Change
Negative	No Change	Blue

Conclusions:

1. The positive pole shows an acid reaction (Blue litmus changed to red)
2. The negative pole shows an alkaline reaction. (Red litmus changed to blue.)

Discussion:

These are important reactions and are made use of clinically Tissue can be destroyed as the result of these reactions The sodium hydroxide which is found at the negative pole has a caustic action on the tissues when concentrated by a suitable electrode for that purpose. Similarly, an acid concentration is produced at the positive electrode. Tissue destruction by the use of these reactions is known as *Electrolysis* by some and *Surgical Galvanism* by others. It would seem that the term *Electrolysis* is the more nearly correct aod hence should be the one of choice.

EXPERIMENT 4—ION TRANSFER

Object:

To demonstrate the law that *unlike charges attract and like charges repel.*

Theory:

In an electrolytic solution, through which a direct current flows, such as that of potassium iodide, the positive ions or cations are attracted toward the negative pole or cathode. On reaching the pole, they lose their charge, becoming chemically active atoms or radicles. They then evolve as a gas, precipitate, or form new combinations with other atoms present. Similarly, the negative ions or anions are attracted toward the positive pole or anode, lose their charge, precipitate, evolve as a gas, or form new combinations

Apparatus:

1. 8 ozs. 20 per cent solution of potassium iodide
2. Direct current generator aod set of conducting cords

3. Several white blotters
4. Two wood spring clothesline clips

Procedure:

A.
1. Saturate a white blotter with potassium iodide solution
2. Connect conducting cords to patient's terminals of generator.
3. Hold the conducting cord tips firmly with the clips for insulation so as to prevent shock to the experimenter. Draw the tips down the length of the blotting paper. Raise the current intensity just high enough to produce the iodine stain. Do not use current great enough to produce a burn on the blotting paper.
4. Record which pole of the generator produced the characteristic iodine stain

B. Reverse polarity without changing the current intensity control. Move the cord tips slowly and gently over the paths previously traced. Be sure not to press hard enough to abrade the paper surface Continue until one inch of the original iodine stain has disappeared Note that an iodine stain appears under the other electrode, which is now the positive electrode.

Observations:

A. Demonstrating that unlike charges attract each other.

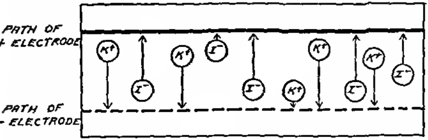


FIG 5 *Attraction of Unlike Charges* Potassium iodide dissociates into K^+ ions and I^- ions The I^- ions are attracted to the positive electrode as shown by the liberation of iodine

Draw a diagram similar to that of Fig 5 in your notebook and indicate migration of the K^+ and I by means of lines

What color is the positive path? Brown

What color is the negative path? No color

What law does experiment demonstrate? The attraction of unlike charges

B. Demonstrating that like charges repel

When the negative electrode is applied and moved lightly over the iodine stain, the brown stain should begin to disappear, and at the same time a brown stain should begin to appear beneath the electrode which is now positive. The potassium atoms liberated at the negative pole react with the free iodine in the presence of water to form potassium hypoiodite and potassium iodide with the liberation of hydrogen. The stain disappears with the potassium and iodine compounds going into a colorless solution Fig 6

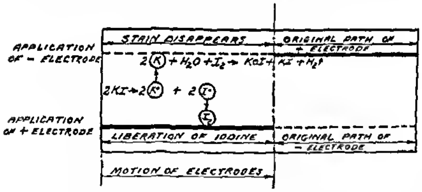


FIG 6 *Repulsion of Like Charges* On reversing the polarity of the electrodes and retracing their paths, the original brown iodine stain disappears and an iodine stain appears under the other electrode Potassium ions are attracted to the now negative pole and are liberated there as chemically active atoms The potassium atoms in the presence of water combine with the iodine to form potassium hypoiodite and potassium iodide with the liberation of hydrogen At the same time iodine ions are attracted to the positive pole and there liberated as atoms of iodine Both a force of repulsion and one of attraction act simultaneously on an ion When the ion is close to a pole having the same charge as the ion, the force acting on the ion is primarily that of repulsion If the charge on the pole is unlike that on the ion, the force is then dominantly that of attraction

Conclusions:

The liberation and precipitation of iodine from a clear, colorless solution of potassium iodide at the positive pole is demonstrated by the appearance of the typical brown stain. The fact that electrically negative ions, the iodine ions, were liberated at the positive pole, is evidence of the law *Unlike charges attract and like charges repel.*

Discussion:

The introduction of ions into the tissues for therapeutic purposes is known under such terms as *ionic medication, ionization, iontophoresis,* and *ion transfer.* If positive ions are required, they are introduced into the tissues by means of the positive direct current; if negative ions, the negative direct current. Any ion can be introduced by using a direct current of the same polarity as the ion

EXPERIMENT 5—EFFECTS OF DIRECT CURRENT ON PROTEIN

Object:

To demonstrate protein changes occurring in the neighborhood of the positive and negative electrodes.

Theory:

At the positive electrode, a concentration of hydrogen ions [H^+] occurs, which means increased acidity The increased acidity brings about coagulation of protein. At the negative electrode, there is a concentration of hydroxyl ions [OH^-], which produces liquefaction of protein.

Apparatus:

1. Direct current generator with conducting cords properly connected.
2. One 10-minute hard-boiled egg (shelled).

3. Two pieces of bright copper wire
4. Two electrode clips
5 Knife.

Procedure:

1. Insert a wire approximately ¾-inch into each end of the egg.
2 Connect these wires to the conducting cords, which are connected to the generator.
3. Allow from 15 to 30 ma of current to flow for 15 to 20 minutes
4 Remove the cords connected to the copper wires without disturbing the wires inserted in the egg
5. Suspend the egg by means of the copper wire which was connected to the positive terminal of the generator
6 Attempt to suspend egg by the other copper wire
7 Remove wires and section egg along a longitudinal plane which will expose the current path
8 Record your results and observations

Observations:

From your observations answer the following questions Then compare these answers with the observations recorded in Table 3

A Positive Electrode
  1 Did you observe any air bubbles forming in the region of the copper wire?
  2 Any color change?
  3 Was the copper wire removed easily?
  4. Probe the egg in the region of the current path and then some remote part of the egg Note any difference in the two parts of the egg

B Negative Electrode
  1 As in "A" above
  2 As in "A" above
  3. As in "A" above
  4 As in "A" above

TABLE 3

	Positive electrode (A)	Negative electrode (B)
(1)	A few bubbles of free O_2 gas	Many bubbles of free H_2 gas
(2)	Green color, an oxysalt of copper deposited in current path	No color change
(3)	No When removed, much protein adhered	Yes Came out with ease and as bright as when inserted
(4)	Hard and sclerotic in current path, coagulated by acid	Translucent in appearance, indicating liquefaction by hydroxyl radicle

Conclusions·

1. The positive pole produces coagulation of protein.
2. The negative pole produces liquefaction of protein.

Discussion:

Both these reactions are employed by clinicians for the destruction of tissues. This procedure is known as *Electrolysis* or *Surgical Ionization*. It is the method of choice where cosmetic effects must be considered, e g , about the face. The degree and rate of coagulation or liquefaction can be easily controlled, and this is the outstanding advantage of electrolysis.

At the positive electrode, there was liberated an hydroxyl radicle which combined with the copper of the electrode to form an oxysalt of copper This reaction, plus the coagulum that is formed, is made use of in such treatments as copper ion transfer to the cervix, zinc ion transfer to ulcers, and zinc ion transfer for hyperesthetic rhinitis. Undoubtedly, the therapeutic results obtained are due to a combination of the coagulum and the deposition of the metallic salts. Eventually, the coagulum sloughs, leaving a clean, granulating surface which heals with a minimal, pliable scar formation.

EXPERIMENT 6—EFFECT OF CHANGE OF POLARITY

Object

To demonstrate the effect on protein of reversing the polarity of an electrode

Theory

It was demonstrated in the previous experiment that protein coagulation occurs in the region of the positive electrode, and liquefaction at the negative electrode It was noted that the positive copper wire electrode was "stuck" or adherent to the protein, and when forcibly removed, protein adherred to it By reversing the polarity of this wire electrode, the negative electrode effect namely, liquefaction, permits ready removal

Apparatus

1 Direct current generator with conducting cords
2 Small piece of lean beef, approximately 2 by 2 by 1 inches
3 Two bright copper wire electrodes
4 Patient's connecting clips

Procedure

1 Insert the copper wire electrodes at opposite ends of the meat
2 Attach a patient s connecting clip to each wire and connect to the generator by means of patient's conducting cords
3 Apply current of from 15 to 30 ma for at least 15 minutes
4 Decrease current flow to zero and attempt removal of positive wire electrode
5 Change polarity switch, thereby reversing the polarity of the electrodes
6 Raise current to approximately 15 ma and gently manipulate the electrode until it is finally released
7 Reduce current to zero and switch generator off

Observations

The positive wire electrode was found to be firmly adherent to

the beef after the current flowed for 15 minutes. The color changes around the positive electrode were not so apparent as in the egg, because of the initial red color of the beef. Nevertheless, an oxysalt of copper was deposited in the meat adjacent to the electrode.

A few minutes after the change of polarity, the wire electrode was easily removed. Liquefaction of the adherent tissue was brought about by the alkaline reaction at this pole, when its polarity became negative.

Conclusions:

When the positive electrode becomes adherent to protein, it can be removed without resorting to force by merely changing its polarity.

Discussion:

This experiment has a very practical application There are technics of treatment in which a positive bare metal electrode is brought into direct contact with mucous membranes. Relatively high intensities of current are used for periods of from 20 to 30 minutes. At the termination of the treatment, the metal electrode or sound would be difficult to remove without employing force. Therefore, before attempting to remove the electrode, it is necessary to proceed as follows:

1. Reduce current intensity gradually to zero; thus the patient will be protected from disagreeable muscular contraction when the polarity switch is changed.
2. Reverse polarity switch.
3. Raise current intensity gradually to desired level, which is approximately 5 to 10 ma.
4. *Gently manipulate electrode until it ceases to be adherent* to the tissues.
5. Reduce current to zero, remove electrode, and switch generator off.

EXPERIMENT 7—SENSORY EFFECTS OF THE DIRECT CURRENT

Object

To determine the sensory effects produced by the direct current

Theory

There is no theory that will adequately explain the empiric observations of the older workers in this field, that positive direct current produces sedative effects and that negative direct current increases irritation However, it is well known that the threshold of nerve conduction is raised in an acid medium It was shown in Experiment 3 that there is an acid reaction in the tissues at the positive electrode It may be that this explains in part the analgesic effects observed

Apparatus

1 Direct current generator and accessories
2 Two 1 inch circular absorbent disk electrodes attached to handles

Procedure

1 Connect the two electrodes to the terminals of the generator *Do not permit subject to learn the polarity of the electrodes*
2 When the two electrodes are thoroughly saturated with a hot 1 per cent saline solution, apply an electrode to the anterior surface of each forearm of a subject Maintain firm and uniform contact of the electrode with the skin
3 Raise the current GRADUALLY until the tolerance of subject is reached *Be sure not to move electrodes from now on until the current is switched off*, otherwise the subject will receive an electric shock
4 Allow the current to flow for some few minutes or until the subject is certain which electrode is the less irritating Before turning off the current or removing the electrode be sure to reduce current GRADUALLY to zero otherwise subject will experience a severe shock

5. Repeat test on several subjects.
6. Prepare a table similar to Table 4 for the recording of observations.

TABLE 4

Subject	MA (Tolerance)	Reaction	
		Pos Electrode	Neg Electrode
1	18	Mild discomfort	Marked discomfort
2	20	Marked to Moderate to Mild	Moderate to Moderate to Marked
3	25	Moderate	Marked

Observations:

1. Some subjects experienced greater discomfort initially at the negative electrode. (Subjects 1 and 3, Table 4).
2. Other subjects experienced greater discomfort at the positive electrode, but, as time passed, the discomfort became less pronounced, and finally these subjects definitely experienced greater irritation at the negative electrode. (Subject 2, Table 4).
3. There was observed a marked erythema under both electrodes: well defined under the positive electrode, but diffuse with occasional wheal formation under the negative electrode.

Conclusions:

Surface irritation is present at both positive and negative electrodes, but if the current flows for a sufficient length of time, more irritation will be felt at the negative electrode.

Discussion:

The foregoing experiment does not substantiate the hypothesis that the positive direct current is definitely sedative, although

greater irritation was experienced at the negative electrode The marked irritation at the negative electrode may be due to the alkaline reaction at that pole The skin is known to be far more sensitive to alkalies than to acids

It is also interesting to note that all subjects do not agree at the beginning of the experiment as to which electrode produces the more marked irritation The difference in response is probably due to individual variations in skin resistance It has been our observation that those subjects whose skin resistance is high nearly always complain initially of greater irritability at the positive electrode, and only after their skin resistance decreases do they agree that the negative electrode causes greater discomfort It would appear then that we should never increase the current rapidly in the case of those patients with high resistance Current intensity should only be increased as the skin resistance of the patient decreases Women seem to have a higher skin resistance than men, and this may account for their greater apprehension of treatment

That nerve irritation can often be relieved by using positive direct current applications seems to be a not uncommon clinical experience Irritable tissues such as muscles and nerves do not conduct impulses readily in an acid medium, and this fact may have a bearing on the observed alleviating effects

EXPERIMENT 8—VASOMOTOR EFFECTS OF THE DIRECT CURRENT

Object

To demonstrate the vasomotor effects produced by direct current

Theory

The positive pole is said by some of the older investigators to produce vasoconstriction, and the negative pole vasodilation[1] It is not possible to demonstrate experimentally the vaso

[1] Bigelow Massey An International System of Electrotherapeutics F A Davis Co Philadelphia.

constricting properties of the positive direct current. The fact is that both positive and negative direct current will produce vasodilatation but in varying degree and persistency for different individuals.

Apparatus:

Same as in Experiment 7.

Procedure:

Same as in Experiment 7.

Observations:

The reactions obtained in Experiment 7 can be used to illustrate the vasomotor effects of the direct current. No evidence of vasoconstriction was observed under either electrode. The initial hyperemia, as denoted by the redness, appeared approximately the same under both electrodes at the completion of the experiment. Some differences were noted: first, that the area of redness was diffuse at the negative electrode; second, that a wheal was raised at the negative electrode if the current intensity had been high; and third, that the redness was restricted to the area under the positive electrode.

TABLE 5

Electrode	Elapsed Time in Hours			
	0	8	16	24
Positive	Marked and circumscribed	Moderate	Slight	Gone
Negative	Marked and diffuse	Marked	Moderate	Very slight

After 12 to 24 hours, the hyperemia beneath the negative pole may still be well defined, while that beneath the positive pole probably will have disappeared. The change in the degree of hyperemia will in the majority of cases progress as indicated in Table 5.

Conclusions:

We were unable to demonstrate any vasoconstricting action of the direct current Hyperemia was observed under both electrodes, but was maintained for a much longer time under the negative electrode.

Discussion:

Lewis and Grant[2] have showo that when the skin is traumatized by chemical, mechanical, or electrical means, a histamine-like substance, which they designate as substance "H", is liberated This substance causes dilatation of the capillaries, and if the injury is severe enough, the histamine-like substance produced is sufficient to cause a change of capillary permeability to the extent that a wheal is formed Such a mechanism would be adequate to explain tbe hyperemia and wheal formation observed in this experiment

EXPERIMENT 9—POLARITY EFFECTS OF THE DIRECT CURRENT ON MUSCLE CONTRACTION

Object:

To demonstrate the normal polar formula for muscle contraction

Theory:

A normal muscle in contact with the negative electrode will give a single twitch or contraction when the switch or key is suddenly closed, provided the current that flows is of sufficient intensity. This is known as the ***Cathodal*** (*negative*) *Closing Contraction* If the muscle is connected to the positive pole, it is possible to secure a similar contraction when the circuit is suddenly closed, provided, however, that the intensity of current is sufficiently high This is called the ***Anodal*** (*positive*) *Closing Con*

[2] Lewis, T, and Grant, D: Vascular Reactions of the Skin Heart, 11 209 1924

traction. Increased irritability at the negative pole is known as *catelectrotonus* and decreased irritability at the positive pole is known as *anelectrotonus.* The complete normal muscle polar formula is: CCC > ACC > AOC > COC, the terms AOC and COC meaning respectively *Anodal Opening Contraction* and *Cathodal Opening Contraction.* For the purpose of clinical application, we need consider only the closing contractions, expressed by the formula CCC > ACC. This formula means that for the same current intensity the cathodal (negative) closing contraction is greater than the anodal (positive) closing contraction.

Apparatus:

1. Direct current generator and conducting cords.
2. Make and break key.
3. Small ½- to ¾-inch electrode for muscle stimulation, illustrated in Fig 23, page 87.
4. Dispersive electrode, approximately 4 by 6 inches.
5. Tumbler of water.

Procedure:

1. Prepare the bicep muscle of either arm for stimulation. Subject must have the arm relaxed, and the forearm in the mid position and at right angles to the upper arm.
2. The dispersive electrode, thoroughly saturated in hot water, is placed under the forearm of the opposite arm.
3. The ½-inch muscle testing electrode, attached to a make-and-break key, is connected directly to the generator. The electrode, thoroughly saturated and comfortably warm, is applied to the motor point of the bicep muscle. *See Motor Point Chart, Fig. 24, page 95.* While the make-and-break key is repeatedly closed and released, the current intensity is gradually increased until a minimal muscle con traction is observed or felt. The degree of contraction should be so slight that with the least reduction of the current the contraction will disappear. The amount of current to secure this minimal contraction is called the threshold current, or as designated by Lapicque, the *rheobase.*

4. Read the milliammeter just as the muscle contracts Note the polarity and record your observations in Table 6. Change the polarity of the muscle stimulating electrode, and repeat the procedure.

Observations:

TABLE 6

Subject	CCC			ACC		
	1	*2*	*3*	*1*	*2*	*3*
Ma required for minimal contraction	1 5			3 0		

Conclusions:

Less current is required to produce a given minimal contraction of normal muscle when the cathode is closed than when the anode is closed Hence, for the same current value, the *cathodal closing contraction* will be greater than the *anodal closing contraction*, or CCC $>$ ACC.

Discussion:

Normal muscles generally respond more vigorously to the negative direct current. The normal muscle can be stimulated repeatedly by merely opening and closing the make-and-break key.

In certain pathological conditions, however, one may find the normal polar formula reversed, that is, CCC $<$ ACC. Under such conditions, a muscle will respond more readily to the stimulus of the positive pole.

EXPERIMENT 10—RESISTANCE TO THE FLOW OF DIRECT CURRENT

Object:

To compare the resistance to the passage of direct current offered by:

(a) Distilled water.
(b) Tap water.
(c) Salt solution.

Theory:

All conductors of electricity offer more or less resistance to the flow of an electric current. The electrical unit of resistance is the *ohm*. A conductor has a resistance of one ohm if a current of one ampere (1000 milliamperes) flows through it on impressing an electromotive force of one volt. The conductance of a conductor is the reciprocal of its resistance, or one divided by the resistance. The unit of conductance is the *mho,* and is the conductance of a conductor whose resistance is 1 ohm. If the resistance is high, the conductance will be low. We usually describe the current carrying ability of a conductive material in terms of its specific conductance or conductivity. The higher the conductivity of a material the lower its resistance to the passage of an electric current. Conduction of an electric current through a solution or a gas is dependent not only upon the presence of ions, but also upon their velocity. Conduction in a solid conductor depends upon the number of free ions present and their mobility.

Apparatus:

1. Direct current generator, conducting cords, and a voltmeter.
2. 500 cc. beaker.
3. Distilled water.
4. Salt.
5. Two metal foil strips, 4 by ½ inches
6. Two patient's electrode clips.

Procedure:

A. *Distilled Water*
   1. Pour 250 cc of distilled water into the beaker.
   2. Place the metal foil strips over the edge of the beaker with ends immersed to a depth of ¼ inch.
   3. Connect electrodes to the generator by means of the conducting cords and electrode clips.
   4. Set the current intensity control at mid-point.
   5. Record the current indicated on the milliammeter of the generator, and the voltage measured by the voltmeter connected across the electrodes.

6. Turn current off but do nnt disturb the electrodes in the beaker nor the setting of the current intensity control. Disconnect the conducting cords at the electrode clips and discard the water.

B. *Tap Water*

1. Pour 250 cc. of tap water into the beaker, replace the conducting cords, and record the ma. and voltage when the current is turned on.
2. Turn current off. Be sure that meter is now switched to read high current values (0 to 150 ma.).

C. *Tap Water Plus Salt*

1. Place a small amount of salt on the end of a spatula and dissolve it in the beaker of tap water.
2. Turn on the current and read the ma. and voltage registered.

Observations:

Record current and voltage readings in Table 7.

TABLE 7

Experiment	MA	Volts	Resistance (Ohms)	Conductance (Mhos)
A Distilled Water B Tap Water C. Tap Water and NaCl				

Compute the resistance and conductance of distilled water, tap water, and salt water from data found and recorded in Table 7. In the computation, volts must be divided by amperes to obtain ohms. The current values that were measured are in milliamperes The milliampere is one-thousandth of an ampere.

To find resistance in ohms, divide voltage by current in amperes. This relation is known as ***Ohm's Law.*** It expresses the relationship which exists between current, voltage, and resistance. It may be written in three forms:

1. Amperes $= \frac{\text{Volts}}{\text{Ohms}}$; that is, $I = \frac{E}{R}$

2. Volts $=$ Amperes $\times$ Ohms; that is, $E = I \times R$

3. Ohms $= \frac{\text{Volts}}{\text{Amperes}}$; that is, $R = \frac{E}{I}$

To find conductance in mhos, divide 1 by the resistance in ohms. Also compute resistance and conductance of solutions studied in Experiment 1, completing Table I, page 10.

Conclusions:

To secure the maximum flow of current for a given voltage the resistance must be reduced to a minimum.

Discussion:

Electrical resistance is an important factor in the application of electric currents to the body. An understanding of the effect of resistance on current flow will suggest means of minimizing discomfort and painful treatments Dry skin has a very high resistance to the passage of a direct current. Wet and perspiring skin has a much lower resistance, but still relatively high in comparison with that of other tissues. In addition, skins vary a great deal; some are quite moist with a sensible perspiration, while others are quite dry. A subject's mental condition will influence the skin conductivity and resistance, and so will certain pathological conditions. To ascertain whether the subject's resistance is high pass approximately 5 ma. of current and watch the milliammeter. If the patient's resistance is high, the meter will show a much higher current reading in a very few minutes than it did initially, possibly as high as 10 ma. The current intensity should not be raised for such patients until the meter shows a fairly steady reading, indicating that the resistance has been lowered to a basic level.

Because of skin resistance, it is an excellent idea to precede the current application with some form of heat for the purpose of inducing perspiration (an excellent electrolyte) and of increasing

the blood supply locally to produce an active hyperemia Further more, all electrodes should be saturated with hot and not cold electrolytic solutions It is important that the influence of resist ance on the flow of current and the effect of a rapid decrease in resistance on the patient's comfort be fully realized, and that procedures such as those described above for reducing skin re sistance to a basic level be taken

EXPERIMENT 11—CONVERSION OF ELECTRICAL ENERGY INTO HEAT ENERGY (Joule's Law)

Object

To demonstrate the conversion of electrical energy into heat energy

Theory

Electrical energy can be converted into energy of other forms When a direct current traverses an electrolytic solution, heat is produced The amount of heat energy developed per unit time depends on the intensity of the current and the ohmic resistance impeding the flow of current The total heat energy liberated will depend on the time the current flows Joule's Law is a quantitative relationship giving the gram calories of heat developed in a con ductor in terms of the current flow, the resistance of the conductor, and the time the current is permitted to flow

Joule's Law

$H = 0\,24\ I^2\ Rt = 0\,24\ EIt$ in which

H = gram calories

I = current in amperes

R = resistance in ohms

t = time in seconds

E = voltage drop in volts

1 gram calorie = the amount of heat required to raise the temperature of 1 gram of water 1° C, more precisely the

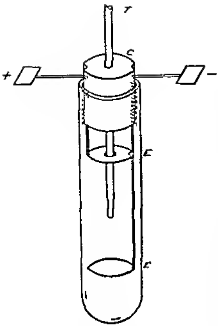


FIG 7 Arrangement of apparatus for Experiment 11 *E E* two copper electrodes constructed as illustrated and connected to a source of direct current by means of enamel insulated wire The upper surface of the upper electrode and the under surface of the lower electrode may be insulated by enamelling This will assist in restricting the current flow to the electrolyte between the two inner surfaces of the electrodes *T* is a thermometer with bulb midway between the electrodes and *C* a perforated and slotted cork to hold thermometer and electrodes in position.

amount of heat required to raise the temperature of 1 gram of water from 15° C to 16° C

Apparatus

1 One large extra wide mouthed test tube
2 One laboratory thermometer
3 Two special electrodes, as illustrated in Fig 7

Procedure

1 Fill the large test tube with tap water
2 Place one electrode in the water near the bottom of the test tube and connect to one terminal of the generator by means of an enamel insulated wire
3 Place the second electrode in the water near the top of the test tube and connect to the other terminal of the generator (See Fig 7)
4 Place a thermometer in the solution and record the temperatures when stable
5 Adjust current control to 20 ma with 30 ma as a possible

TABLE 8

Time Min	Current (I)	Volts (E)	Watts (EI)	Sec (t)	Watt sec (EIt)	Gram Calories (24 EIt)	Temp °C	Temp Rise	Temp rise ÷ gram calories
0	020 amp	55 v	1 1	0	0	0	23 4	0	—
5	020 amp	55 v	1 1	300	330	79 2	24 8	1 4	0177
10	020 amp	55 v	1 1	600	660	158 4	26 2	2 8	0177
15	020 amp	55 v	1 1	900	990	237 6	27 4	4 0	0169
20	020 amp	55 v	1 1	1200	1320	316 8	28 5	5 1	0161

maximum Do not vary current after a value has ooce been decided upon

6 Record the water temperature at five minute intervals

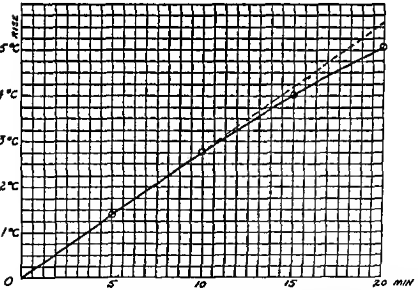


FIG 8 Temperature rise versus time plotted from the experimental data in Table 8 According to Joule s Law this relationship is linear but the graph of the experimental data deviated from linearity because no correction was made for radiation and other losses

7. Prepare a table such as Table 8. Compute and tabulate the data called for.
8. Plot temperature rise against time as illustrated in Fig 8.

Conclusions:

The electrical energy used in transporting the ions in the solution is converted into heat energy in accordance with Joule's Law. The temperature of the water rose from *23.4* degrees to *28.5* degrees, Centigrade.

Discussion:

Turrell believes that the beneficial therapeutic effects of the direct current are in large part due to the heat generated in the tissues by the passage of the current. This he claims is particularly true in those pathologies in which the temperature of the tissues is subnormal as is so often true in arthritic conditions. With the generation of heat in tissues there occurs a vasodilatation and an increased blood supply with a consequent increase in temperature. As a result there is a relaxation of muscle spasm and a consequent decrease of pain.

Turrell states that the best results are obtained in old standing chronic conditions where the local circulation and nutrition need improvement. It may well be that these views, which have been given scant attention in this country, should no longer pass unnoticed.

Practical Problem:

Compute the number of calories introduced in the following direct current application. Patient received 75 ma. at 100 volts. Treatment was given for 20 minutes. (Answer: 2160 gram calories)*

$E \times I \times t \times 0.24 = 100 \times 0.075 \times 20 \times 60 \times 0.24 = 2160$ gram-calories.

* The instructor should formulate several such problems for solution by *students of the class*

V SUMMARY OF DIRECT CURRENT REACTIONS

	At Positive Electrode	At Negative Electrode
Water Electrolysis	Liberation of free O_2 Gas	Liberation of free H_2 Gas
Litmus Paper (H Ion Concentration)	Acid	Alkaline
Potassium Iodide	Liberation of Iodine and repulsion of Positive Ions	Liberation of Potassium and repulsion of Negative Ions
Protein	Coagulation	Liquefaction
Sensation	Sedation (?)	Irritation
Vasomotor Effect	Vasodilatation Vasoconstriction (?)	Vasodilatation
Muscular Contraction	Decreased muscular irritability, termed *Anelectrotonus*	Increased muscular irritability termed *Catelectrotonus*

PART A DIRECT CURRENT

SECTION TWO TECHNIC OF APPLICATION

I TYPES OF ELECTRODES AND THEIR PREPARATION, CURRENT DENSITY, AND ELECTROTHERAPEUTIC PRESCRIPTION

A *Types of Electrodes Used* The direct current is applied to the body by means of appropriate electrodes One electrode is applied for a specific therapeutic effect and hence is called the *active* electrode A second electrode is applied with the object of completing the current circuit and is known as the *dispersive* electrode

1 *The Active Electrode* The active electrodes employed vary widely in shape, size, and construction Fig 9 illustrates a number of the electrodes now in general use The active electrode may be

a *Needles*
  (1) Steel (cambric needle)
  (2) Platinum iridium (for hypertrichosis)
    (a) sharp
    (b) bulbous pointed
b *Sounds of Copper or Silver*
  (1) Olivary for urethral electrolysis
  (2) Uterine
  (3) Cervical
  (4) Vaginal and prostatic
c *Roller of Metal Covered with Chamois for Labile Galvanism*
d *Moisture Retaining*
  (1) Of absorbent material for carrying ionic solutions, such as
    (a) Cellucotton
    (b) Asbestos paper
    (c) Canton flannel

e. *Special*

(1) Muscle testing electrode which is equipped with a make-and-break key

(2) Hand electrode

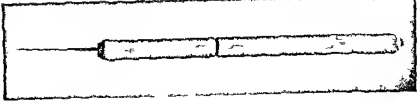
(3) Aural electrode

(4) Antrum electrode

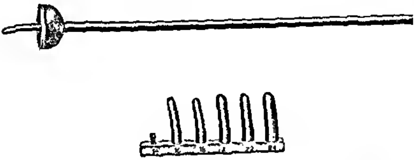
2. *The Dispersive Electrode.* This usually consists of a flexible perforated piece of metal attached to absorbent felt or encased in some highly absorbent material which will hold moisture for some considerable time. A representative dispersive electrode is also shown in Fig. 9.

The term *dispersive electrode* describes its purpose. Its surface area is much greater and hence the current density is much less than that of the active electrode. Other terms for the dispersive electrode are *inactive* and *indifferent;* but it is impossible for one electrode of the direct current to be active and one inactive. Both electrodes carry the same total current, but the current density, which is the current per unit area, of the larger dispersive electrode is not more than half that of the active electrode; hence reaction at that electrode is minimized.

B. *Preparation of Electrodes.* With few exceptions the electrodes are saturated in some conducting solution. The solution into which the electrodes are immersed should be quite hot. The dispersive pad is saturated preferably in a hot 1 per cent solution of sodium bicarbonate or salt. If the electrodes are in frequent use it is well to keep them continuously in a solution to which a suitable disinfectant has been added. Inasmuch as most of the electrodes used require some time for complete saturation this should save considerable time. It is important, however, that the electrode be immersed in a *hot* solution prior to use, for by the *time the electrode is applied to the skin surface it will be at a* comfortable temperature. The warmth of the electrode will tend to produce vasodilatation, inducing a lowered skin resistance to the flow of current. Electrodes are connected to the source of current by suitable flexible conductors, known as *patient's electrode cords.*



A



B

C

F

FIG 9 Representative active and dispersive electrodes

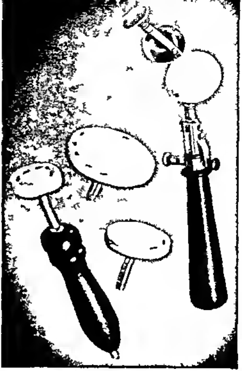
A. Electrode holder and platinum iridium needle with bulbous point for electrolysis in hypertrichosis

B Electrode for copper ion transfer to the cervix and uterus Consists of a copper cup to which is attached any one of the various sized copper sounds illustrated

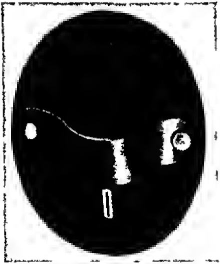
C Electrode for copper ion transfer to the vagina. Consists of a perforated copper ball attached to an insulated tube which is provided with a nozzle for connection to a suspended container of copper sulphate solution.

F Handle for muscle testing electrode equipped with a make and break key

D



E



G

I

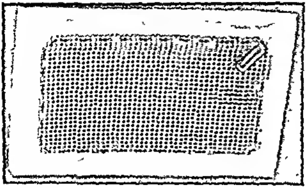
Fig 9 Representative active and dispersive electrodes

D Roller electrode for labile application

E Wood handle with two terminals one for the cord tip and the other threaded to receive various types of electrodes as illustrated

G Hand electrode for making labile application.

I Multiple connector



H. Typical dispersive *electrode* made of flexible perforated metal covered on one side with *absorbent* felt.

J. Electrode connecting clip.

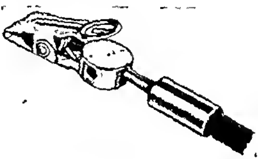


Fig 9. Representative active and dispersive electrodes.

C. *Electrode Application*

1. *The Patient*

a. As explained under *Discussion* in Experiment 10, the skin resistance can be markedly reduced by the simple measure of applying some form of heat to the area of application. If possible, this should always be done. Such a simple measure might well be the one factor to make comfortable an otherwise uncomfortable application.

b. The patient should be arranged in a comfortable and suitable position. The parts to be treated should be well supported. Adequate protection against soiling the clothing should be provided by the free use of towels and rubber sheets.

c. *The Skin*

(1) *Abrasions.* Examine the skin carefully for abrasions. Do this so painstakingly that the patient will become aware of your carefulness. When abrasions or skin lesions are present, the current tends to concentrate at such points and produce a serious electrolytic burn. Such lesions, if present, should be covered with adhesive tape, of a size sufficient to cover the lesions.

(2) *Oily and Dry Skins.* If the skin is unusually greasy, it should be washed with ether, alcohol, or soap. A dry skin is extremely resistant to the flow of current; hence the part with such skin should be immersed in hot water, if possible, or exposed to some form of heat prior to applying the electrode.

d. *Position of Electrodes.* Electrodes must be kept in firm, uniform contact with the skin throughout the entire treatment. Uneven contact or uneven pressure is a prolific and often unrecognized cause of discomfort, excessive current concentration, and painful electrolytic burns. Contact can be either too light or too heavy. Good contact can usually be secured by holding the electrode in position with a well applied pure gum rubber bandage or well placed sandbags. When the patient's position for treatment permits, the dispersive electrode may be placed under him, his weight assuring adequate contact.

D. *Current Density of Electrodes (Dosage)*

1. *The Active Electrode.* The normal skin tolerates a current density of approximately one to two ma. per sq. in. of electrode surface. Ulcerated surfaces or denuded areas will tolerate a current density of about four ma. per sq. in. The denuded areas have a much lower resistance and greater conductance because the highly resistant skin surface is absent; hence more current can be tolerated per unit area. It must be borne in mind that these values are not necessarily absolute but constitute a guide.

2. *The Dispersive Electrode.* For obvious reasons the dispersive electrode is always larger than the active. The current per unit area of the dispersive electrode should be not more than one-half that of the active electrode. This can be achieved by making the area of the dispersive electrode at least twice that of the

active electrode Table 9 gives the size of dispersive electrode to be used for various total current values of the active electrode The dispersive electrodes as outlined in Table 9 should never be smaller than indicated, but they may, and, in fact, should be larger if possible—the larger the better, because the current per unit area at the dispersive electrode will consequently be smaller,

TABLE 9

Total Current of Active Electrode	Size of Dispersive Electrode
1 to 25 ma	24 square inches (4×6 inches)
25 to 50 ma	48 square inches (6×8 inches)
50 ma and higher	120 square inches (10×12 inches)

and undesirable current effects at that electrode will thus be minimized

E *Rules for Administration of Treatment.* Before turning on the current to the patient, the technician should observe:

1. That the meters read on the correct scale.
2 That the current intensity control is at the zero position
3 That the patient's conducting cords are properly connected and the circuit completed.
4. That the polarity is correct for the active electrode.
5. That the line plug, when the equipment utilizes power from the line, is securely in place so that there is no possibility of the circuit being accidentally broken during treatment.

The current switch is then turned on and the current intensity gradually increased As the current intensity is gradually increased, there will be experienced a sensation of tingling. The current intensity should not be increased at this stage until the tingling sensation has almost subsided. As the current intensity is further gradually increased, there will follow a sensation of warmth It is good technic not to increase the current until the milliammeter needle remains practically stationary at a given current intensity.

The first treatment shnuld always be given with the least possible discomfort to the patient, even thnugh the amount of current called for by the prescription cannnt be secured. During the first treatment the patient may be apprehensive, but wben nothing occurs to produce undue alarm, fear vanishes and confidence is gained.

F. *The General Electrotherapeutic Prescription.* The physician employing any form of electrntherapy should give a written prescription to be followed by bis technician. In this manner misunderstanding can be avoided, and the prescription becomes a part of the regular patient record for later reference.

The type of information and direction tbat the prescription for treatment should provide for the guidance of the technician is suggested by the following:

1. *The Intensity of the Electric Current.* Tbe ampere is the unit of current measurement, but in medical work this unit is too large; hence the milliampere is used, which is a thousandth part of an ampere.

2. *Voltage.* The voltage is the electrical pressure required to produce a current flow. When all preparations are made correctly, the voltage will be at a minimum for any given current flow.

3. *Polarity.* When using the direct current, the polarity to be used for the active electrode should be stated.

4. *Wavelength or Frequency.* In the case of a direct current, the frequency is of course zero but if the current to be employed is alternating in character, then the frequency to be used should be given. In the case of radiation, the spectral band of wavelengths to be used should be designated.

5. *Skin-Source Distance.* The distance from the source of energy to the skin should be indicated, e g , electrode-skin distance in the case of short wave diathermy, and burner-skin distance in the case of ultravinlet nr infrared radiation. In the case of direct current, applicatinn of the electrodes is made directly to the skin as described under the various technics of application.

6. *The Duration of the Treatment.* The time nf application in minutes or bours sbould be prescribed.

7 *The Frequency of Treatment* The number of treatments per day or week should be given IMPORTANT NONE OF THE FORE GOING FACTORS SHOULD BE LEFT TO THE DISCRETION OF THE TECHNICIAN

G *Precautions to be Observed in Administering Direct Current*

1 Examination of the patient s skin should be made before applying the electrodes and again after their removal This should be done in such a manner that the patient is cognizant of the fact without attention being specifically directed to it

2 If the patient complains of discomfort, it may be due to

a Poor contact of the electrodes

b Uneven contact such as that resulting from excessive pres sure at the edges of the electrodes

If due to poor contact, pressure of the operator's hand on the electrode will eliminate the discomfort If it is due to uneven con tact mere pressure on the electrode will not help In either case, the electrode should be reapplied taking care to eliminate poor and nonuniform contact If there has been an uneven pressure of the electrode during the treatment it will make itself manifest by a marked erythema over this spot

3 Never turn the current off during the treatment, unless the current intensity has first been reduced to zero

4 Warn the patient to notify you of the slightest sensation of burning or of pain

5 Make no applications over areas having a loss of sensation

6 Be sure that no metal part of the electrodes, metal clips or conducting cords comes in contact with the skin

7 Be sure that the electrode pads are uniformly and thoroughly saturated with the solution to be used Nonuniform saturation is a frequent cause of discomfort

8 Regardless of what the optimal current density should normally be, do not exceed the patient s tolerance

H *Simple Method for Polarity Test*

1 Saturate a white blotter with a 10 per cent solution of potassium iodide

2. Grasp the metal tip of each conducting cord with a wood clothesline clip, so that they may be held without producing shock.

3. Draw both tips slowly over the surface of the wet blotting paper.

4. The path traversed by the positive pole will show the typical brown iodine stain There will be no stain beneath the negative pole Fig 5, page (17).

II. Specific Applications

A. *Ion Transfer. Ion transfer, ionic medication, ionization,* and *iontophoresis* are terms used to indicate the introduction of ions, or the exchange of ions within the tissues, for therapeutic purposes by means of the direct current. The value of this procedure is dependent upon the slightly greater penetration of the substances into the tissues than that usually secured by topical applications of the same remedies The theory underlying the treatment was demonstrated in Experiments 1, 2, and 4.

1. *Limitations.* The depth of penetration and the degree of concentration of the substances introduced are limited by the following factors:

a. *Velocity of the ions* All ions do not have the same velocity. The conductivity of an electrolyte depends not only upon the number of ions present but also upon their velocity. Owing to the far higher velocity of the tissue ions and their greater number, the foreign ions, i e , the ions to be introduced, cannot contribute appreciably to the flow of current in the deeper tissues. The foreign ions introduced through the skin lose their electrical charge and precipitate as soluble or insoluble compounds in the superficial tissues.

b. *Circulation.* The speed of the circulating blood will tend to sweep away quantities of these ions into the general circulation before the ions can penetrate appreciably into the deeper tissues

2. *Substances Most Commonly Used.* In Table 10 the substances most commonly used for ion transfer are tabulated.

Metal ions in solution always carry a positive charge, and nonmetal ions a negative charge. Therefore, if it is desired to use the metal ion, the positive pole is applied; and if the non-metallic

TABLE 10

Polarity of Active Electrode	Solution	Ion utilized
Negative	Sodium Chloride	Chloride
	Sodium salicylate	Salicylate
	Potassium Iodide	Iodide
Positive	Zinc sulphate	Zinc
	Copper sulphate	Copper
	Acetyl Beta Methylcholine-Chloride (Mecholyl)	Choline
	Histamine Chloride	Histamine

ion is to be used, the negative pole is applied as the active electrode Certain non metallic organic salts, such as acetyl Beta-methylcholine chloride and histamine chloride, dissociate into positive radicles and negative ions

3 *Preparation of Solutions* Most solutions are used at a one to two per cent concentration If the solutions are used infrequently, they can be made up when needed Hot water should be used so that the solution will be comfortably warm when applied to the skin surface If the solutions are used frequently, then stock solutions of 20 per cent concentration can be made and diluted with hot water as needed

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B *Ion Transfer to Surfaces of the Unbroken Skin*

1 *Application to the Hand, Foot, and Various Joints*

a *The Active Electrode* may be made of cellucotton, asbestos paper, or canton flannel

(1) *Cellucotton* Select a metal foil electrode, 2 to 3 inches wide, and of sufficient length to encircle the joint and overlap about one inch Cut a strip of cellucotton, 2 inches thick, and having exactly the same length and width as the metal foil Place them in a basin, as illustrated in Fig 10a, and carefully pour the required solution over the cellucotton until fully saturated *Caution Do not pour more solution on the cellucotton than can be readily absorbed* Carefully squeeze out any excess solution with the palm of the hand, being careful to keep the upper layer of

tween 25 cc to 40 cc is usually sufficient for one treatment The wet paper should be handled carefully to prevent tearing

When asbestos paper is to be used for the hand, it must be wide enough to include the finger tips and to extend about two inches above the wrist joint It must be long enough so that it can be fitted in between each finger as shown in Fig 11

FIG 11 The hand with fingers widespread is placed on the center of the saturated asbestos paper The paper is next folded over the top of the hand and fitted carefully between the fingers The fingers are then drawn together and the paper smoothed over so that i fits snugly around the entire hand and wrist A strip of ½ inch electrode foil (008 inch in thickness) is then wrapped around in a sp ral with each turn about ½ inch apart over the entire area covered by the paper (From Boerner L Technic of Acetyl Beta Methylcholine Chloride Iontophoresis Physiotherapy Review 17 p 12 Jan Feb 1937)

(a) *Hand* The hand with fingers widespread is placed on the center of the saturated paper The paper is next folded over the top of the hand and fitted carefully between the fingers The fingers are then drawn together and the paper smoothed over so that it fits snugly around the entire hand and wrist A strip of ½ inch metal electrode foil is then wrapped around in a spiral with each turn about ½ inch apart over the entire area covered by the paper Foil, 008 inch in thickness, is to be preferred to the thin burglar tape frequently suggested, because there is no danger of its tearing while being applied, yet it is sufficiently flexible to

FIG 12 Application of asbestos paper electrode to the knee with foil strip in place A metal clip is attached by a connecting cord to the distal end of the foil and to the positive pole of the galvanic generator To prevent concentration of the current at the point of entry it is essential that a small piece of rubber sheeting be placed under the clip (From Boerner, L Technic of *Acetyl Beta Methylcholine Chloride Iontophoresis Physiotherapy Review*, 17, p 12, Jan-Feb, 1937)

make firm contact and strong enough that it may be used many times. Fig 12 illustrates the method of applying the foil strip

A metal clip is attached by a connecting cord to the distal end of the foil and to the proper terminal of the galvanic generator. To prevent concentration of the current at the point of entry, it is essential that a small piece of rubber sheeting be placed under the clip To prevent drying of the paper and to insure close contact, the entire hand is covered with a non absorbent pure gum rubber bandage. Because of its elasticity, care must be exercised in applying the bandage, so that it is not applied too tightly. By including the clip in the bandage there is no danger of the patient

loosening the connection if he moves his hand Electrodes should be so bandaged as to assure even pressure over the entire electrode Uneven, insufficient, or excessive pressure, especially around the edges of the electrodes, must be avoided

Before applying the electrodes, the skin areas should be examined carefully and any break in the skin, including acne

FIG 13 To prevent drying of the paper and to insure close contact the entire electrode is then covered with a non absorbent pure gum rubber bandage Because of its elasticity, care must be exercised in applying the bandage so that it is not applied too tightly By including the clip in the bandage there is no danger of the patient loosening the connection if he should move (From Boerner L Technic of Acetyl Beta Methylcholine Chloride Iontophoresis Physiotherapy Review, 17 p 12 Jan Feb, 1937)

pustules, no matter how small, should be covered with adhesive tape, only sufficiently large, however, to cover the abrasion Collodion may be used in a similar manner Without such insulation the resistance to the current at these points is lowered Since the current takes the course of least resistance, it would concentrate there and cause burns This type of burn is usually deep and slow to heal

After the electrodes have been applied and connected to the machine, all connections in the set up should be checked to be

certain that they are tight in order to prevent any danger of sudden break in the circuit by slight movement of the patient or the machine (This would cause a shock to the patient) The current is now turned on and increased gradually to the desired milliamperage.

(b) *Foot:* Application to the foot is made in a manner quite

FIG 14 The dispersive pad is applied to the back so that all areas are in close contact with the skin A piece of rubber sheeting is placed under it to prevent the moisture from being absorbed by the bedding, and a square rubber air cushion or small pillow approximately the size of the dispersive electrode under that to insure close contact *To prevent burns, care should be taken that no metal touches the patient* (From Boerner, L Technic of Acetyl Beta Methylcholine Chloride Iontophoresis Physiotherapy Review, 17, p 12, Jan-Feb, 1937)

similar to the application to the hand The shape and size of the asbestos paper must of course be such that it will conform to the anatomy of the foot, extending at least two inches above the ankle

(c) *Joints:* The preparation and application of the active electrode to joints is as described in the preceding paragraphs The size should be such that when applied, the asbestos will extend well above and well below the joint Figs 12 and 13

b *Dispersive Electrode* Usually 10 × 12 inches, but it may be of any appropriate size, and should be prepared as already described Protect abrasions or skin lesions with adhesive tape A small inflatable rubber cushion, or a small pillow approximately the size of the dispersive electrode, should be placed under the electrode in the region of the lower lumbar curve to assure uni form contact of the electrode Fig 14 Be sure the upper edge of the electrode, because of the patient's position, does not make better contact than other areas of the electrode Connect the con ducting cord from the dispersive electrode to the proper terminal of the generator Set the milliammeter on the correct scale Slowly increase the current intensity, keeping it, however, well within the patient's tolerance

c *Medication and Polarity Used*

(1) *Sodium Salicylate* A solution of 1 per cent concentration is used The active electrode is saturated with the solution as already outlined The salicylate radicle is the one used When in the ionic state, it carries a negative electric charge, hence, the active electrode is connected to the negative terminal of the generator

(2) *Mecholyl* The active electrode is saturated with a 1 per cent solution of Mecholyl The active electrode is connected to the positive terminal of the generator, because the radicle used, when in the ionic state, carries a positive charge Some, or all, of the following reactions should be secured as a result of the treatment

(a) Flushing of the face and neck
(b) Perspiration
(c) Increased salivation and sometimes lacrimation

Any untoward effects of the drug can be counteracted by hypo dermic injection of 1/100 gr atropine sulphate This counteract ing drug should always be available in case of an emergency

(3) *Histamine* Application may be made by either of the fol lowing methods

(a) The asbestos paper is saturated with a 1 1000 solution of histamine acid phosphate and then applied as already outlined

The active electrode is connected to the positive terminal of the generator.

(b) A 1 per cent histamine ointment is rubbed into previously scarified skin. The skin is then cleansed of the histamine vehicle and covered with a pad moistened with tap water, which is connected to the positive terminal.

d. *Prescriptions*

(1) *Sodium Salicylate*—1 per cent concentration
Milliamperes—2 ma. per sq. in. of active electrode surface; or that tolerated by the skin.
Voltage—Minimum. See 2 under *General Electrotherapeutic Prescription,* page 47.
Polarity—Negative to active electrode.
Time—45 minutes.
Frequency—Daily, or as frequently as three times daily if possible.

(2) *Mecholyl*—1 per cent concentration. Some use 0.2 to 0.5 per cent.
Milliamperes—Current strength should be just sufficient to cause flushing of the face. This usually requires from 20 to 50 ma. according to area of surface covered by electrode.
Voltage—Minimum.
Polarity—Positive to active electrode.
Time—30 minutes.
Frequency—3 times weekly.

(3) *Histamine*—(a) Solution 1:1000 or 1:2000; or
(b) Ointment 1 per cent.
Milliamperes—(a) ½ ma. per sq. in. of active electrode surface.
(b) Some workers advocate total current of 15 ma.
Voltage—Minimum.
Polarity—Positive pole to active electrode.
Time—(a) 1 to 2 minutes.
(b) 3 to 5 minutes.
Frequency—3 times weekly.

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2. *Application to Recent Scar Tissue*

a. *Medication.* One to two per cent sodium chloride solution. The chlorine ion is to be used.

b *Active Electrode*

(1) The active electrode made of cellucotton is saturated with a hot 1 per cent solution of sodium chloride, and cut so that it covers the scar and extends one-eighth of an inch beyond its edges. Over the cellucotton a metal foil electrode, just slightly less in area, is placed. The negative terminal is connected to the electrode by means of a clip or held in firm contact by adhesive tape, and the whole electrode is maintained in position by several turns of pure gum rubber bandage.

(2) The active electrode, consisting of a warm 1 per cent solution of sodium chloride contained in a metal basin, may be used if more convenient. The basin should be no larger than is necessary. The hand or foot is immersed in the solution. The negative terminal is connected to the basin, or, if the basin is enamelled, a 2-inch strip of metal foil should be introduced into the solution and connected to the negative terminal Occasionally current effects are felt at the boundary of the water surface and the skin. This can be overcome by applying vaseline to the skin at this area.

c. *Dispersive Electrode.* Prepare and apply as already described.

d. *Prescription*

Milliamperes—2 ma. per square inch of active electrode surface.
Voltage—Minimum.
Polarity—Negative to active electrode.

Time—30 to 45 minutes
Frequency—Daily if possible or 2 to 3 times weekly

e *Discussion* The caustic action of the negative current was demonstrated in Experiment 3 The caustic action of the sodium hydroxide formed at the negative electrode softens light super ficial scars and also helps in loosening dense and heavy scars making them more amenable to subsequent treatment, such as sustained mechanical stretching exercise and massage According to Cumberbatch the softening of hard scar tissue in the re gion of the cathode may be due to an increase of moisture in the tissue following the passage of the current

Best results are secured by applying the proper combination of these measures Best results will naturally be secured with those scars that have not reached a static stage It is quite essential that such measures as exercise and massage be used in conjunction with this treatment in order that maximum stretching of the contractured scar tissues softened by the direct current be se cured Of the greatest importance is the employment of some mechanical means such as an appropriate brace or splint, worn continuously between treatments to maintain the maximum stretching of the contractured tissues The mechanical means em ployed to secure this effect should exert steady and continuous stretching but not of such magnitude as to produce pain

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C *Ion Transfer to Denuded Surfaces*

1 *Application for Fungus Infections of Hands and Feet* (Modification of Haggard s technic)

a *Medication* One to two per cent copper sulphate solution

b. *Apparatus*

(1) Two rectangular enameled basins about five inches deep.
(2) Two Bain-marie basins for the hands.
(3) One per cent copper sulphate solution.
(4) Copper metal strips, ¾ × 10 inches
(5) Metal electrode clips. Fig 9, page 44.
(6) Multiple connectors Fig 9, page 43.
(7) Generator and patient's conducting cords.
(8) Sodium chloride solution.

c. *Preparation.* Haggard states that a preliminary soaking of the feet or hands for a few minutes in a dilute solution of sodium hypochloride is particularly advantageous in preparing the skin for treatment. The removal of all debris and crusts is essential. Hydrous wool fat applied to denuded areas will prevent socks from sticking to abraded areas of the feet between treatments.

d. *Technic*

(1) *Single Foot.* Place in one of the foot basins a quantity of 1 per cent copper sulphate solution sufficient to cover the infected area. The copper strip is placed in the solution and held to the side of the basin with the metal electrode clip. The patient's conducting cord is connected to the *positive* terminal of the generator and to the electrode clip on the basin. The dispersive electrode is applied by immersing the other foot in the second foot basin, in which a 1 per cent sodium chloride solution sufficient to cover the whole foot and ankle has been placed A metal strip is attached to the basin in the manner described, and connected to the *negative* terminal of the generator.

The dispersive electrode may consist of a hand towel, cellucotton, or similar absorbent material saturated with sodium chloride, and applied to the upper part of the extremity treated. It must be of sufficient size to assure that this electrode functions as a dispersive electrode and not as an active electrode. Electrical contact is made by covering the saturated electrode with metal foil, which is held in place by rubber bandage. The electrode is connected to the negative terminal of the direct current generator by means of an electrode clip and a conducting cord.

(2) *Both Feet* Both feet are immersed in copper sulphate solution as described above By means of a multiple connector, the leads from the foot baths are connected to the positive terminal The two arm baths, each containing a sufficient quantity of 1 per cent sodium chloride solution to cover the entire forearms when immersed, serve as dispersive electrodes, and are similarly connected with a multiple connector, but to the negative terminal

(3) *Hands* For the hands, similar procedures to those described for the feet are employed, but in this case the Bain marie basins contain copper sulphate solution, while the foot baths containing sodium chloride solution serve as dispersive electrodes

e *Prescription*

Milliamperes—Haggard recommends 4 to 6 ma for one hand or one foot, and 8 to 10 ma for both feet or both hands

Voltage—Minimum

Polarity—Positive to copper sulphate solution

Time—Twenty minutes

Frequency—Two to three times weekly

f *Discussion* Haggard, Strauss, and Greenberg advocate the use of a special type of direct current generator for this treatment In our opinion such apparatus is unnecessary and adds only to the cost of a very simple treatment The ordinary direct current generators which are unequipped with electronic current limiting circuits, serve most satisfactorily for this simple treatment The patient should be warned not to take the extremity undergoing treatment out of the solution because of the possibility of a slight shock on the sudden interrupting of the current circuit If there is slight irritation of the skin near the water surface, it can be relieved by applying vaseline to the skin at this area

In our opinion, higher intensity of current might be more effective In copper ion transfer to ulcers, a total current flow of 20 to 50 ma is employed, corresponding to a very high current per sq inch of electrode surface In the treatment of fungus infections, the total current flow of only 4 to 6 ma, as Haggard

recommends, corresponds to an extremely low current density. The current density in milliamperes per square inch is the total current divided by the area in square inches of the skin in contact with the copper sulphate solution. This area in the case of fungus infections is very large. Therefore, it is obvious that the current density, or milliamperes per unit area of the surface treated, is extremely low. Treatment by copper ion transfer of the individual lesions with relatively high current density, using the technic employed for ulcers, may be more effective.

The amount of a metal introduced into the tissues can be computed readily.

Example: A patient is given a 30-minute treatment. Copper sulphate solution is used; the current is 15 ma. How many milligrams of copper are liberated? (Ans. 8.9 mg)

Solution: From the data presented in The Handbook of Physics and Chemistry, the electrochemical equivalents of metals most frequently employed in ion transfer are as given in the following table:

Metal	Electrochemical Equivalent (grams per ampere hour)
Copper (Cu)	1 19
Zinc (Zn)	1 22
Silver (Ag)	4 02

30 minutes = 0 5 hr
15 ma = 0 015 amp
0 5 hr. × 0 015 amp = 0 0075 ampere hours
0075 × 1 19 = .008925 grams or 8 9 milligrams

g. *References*

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2. Haggard, H. W.: Strauss, M J, and Greenberg, L. A.: Fungus Infections of the Hands and Feet Treated by Iontophoresis Copper. J.A.M.A. 112:1229-1232 (April 1) 1939.
3. Greenwood, A. M, and Rockwood, E M.: Iontophoresis of Copper Sulphate in Cases of Proved Mycotic Infection Arch Dermat. & Syph 44.800-803 (November) 1941.

2 *Application to Ulcers*

a *Medication*

(1) One per cent zinc sulphate solution
(2) Mecholyl solution, 0 5 per cent
(3) Histamine, 1 1,000

b *Method*

(1) *Direct Over the Ulcer* The ulcer is thoroughly cleansed A piece of used x ray film, washed free of its emulsion, is placed over the ulcerated area, the ulcer outlined with ink, and the x ray film cut out on the inked outline This piece of film then serves as a template for cutting the active cellucotton electrode to the necessary shape and size, it will also serve as a permanent clinical record of the initial size and shape of the lesion, so that actual progress can be gauged

The floor of the ulcer is covered with one layer of gauze If the ulcer is deep and its floor uneven, it should be built up and leveled with pledgets of cellucotton saturated in zinc sulphate solution The active cellucotton electrode is also saturated in a warm solution of 1 per cent zinc sulphate solution Using the template as a guide, the active electrode is cut one eighth inch beyond the margin of the template, and then applied directly to the ulcer A metal plate of zinc or electrode foil, and of suitable size, is placed in contact with the cellucotton, and the terminal of the positive cord fixed firmly in good contact with it by means of adhesive tape Fig 15 This active electrode can be held securely in place by means of a rubber bandage or sand bags Fig 16 The dispersive electrode is applied to any convenient part of the body as already described

(2) *Indirect* The active electrode of asbestos paper is saturated with a 0 5 per cent solution of Mecholyl, or a 1 1,000 histamine solution, applied above, below, and around, but not directly over the ulcer itself The usual ½ inch foil metal strip is wound around the surface of the asbestos paper, as illustrated in Fig 12, page 55, and connected to the positive pole of the generator Some, however, prefer to apply the electrode directly

FIG 15 (Insert) Application of a cellucotton active electrode to an ulcer Cellucotton is cut to the shape of the ulcer, but about ⅛ inch larger all around Contact is made with cellucotton by a zinc plate

FIG 16 The electrode in Fig 15 is held in place by means of a gum rubber bandage

over the ulcer as well as to the surrounding parts The electrode is retained in position by the usual rubber bandage or sand bag

The dispersive electrode is applied as previously described Following treatment of varicose ulcers, an Una's paste boot, or some similar support, must be applied and worn continuously between treatments

c. *Prescription*

Method

(1) *Direct Application.* Zinc sulphate solution, 1 per cent: 4 ma per square inch of electrode area

(2) *Indirect Application*

(a) Mecholyl, 0 5 per cent.

(b) Histamine, 1:1000

Current intensity sufficient to secure the previously described reaction, usually 10 to 30 ma , page 58

Voltage—Minimum.

Polarity—Positive.

Time—10 to 30 minutes according to area treated.

Frequency—Once every seven to ten days

d *Discussion.* The underlying causes for the ulcer must be sought, and measures taken to correct them If it is an indolent ulcer due to poor nutrition or circulation, the treatment *per se* should prove quite effective If due to varicosities, support to the part may have to be provided Such support can be secured by applying an Una's paste boot.* Sometimes the necessary support is secured by means of an elastic bandage. In the more severe cases, it may be necessary to resort to the use of sclerosing solutions or even ligation

The best results are obtained by a proper combination of therapeutic procedures It is essential that the edges of the ulcer be kept quite clean and that excessive granulations be removed

* Boot is constructed of alternate applications of gauze bandage and Una's paste The formula for Una's paste is

Glycerin 1900 grams

Gelatin 625 grams

Water 1900 c c

Zinc Oxide 250 grams

It is prepared in a double boiler

e. *References*

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3. *Application for Fissures, Fistulae, and Sinuses*

a. *Medication.* One per cent zinc sulphate, or a solid zinc wire electrode.

b. *Method.* The active electrode may be a 1 per cent zinc sulphate solution or a zinc wire electrode, whichever can be used most conveniently. The cavity is filled with zinc sulphate solution, and the positive terminal is connected to a suitable zinc electrode placed in the solution. When the use of the solution is not practicable, a zinc electrode of suitable dimensions and pliability, wrapped in cotton and thoroughly soaked in a 1 per cent zinc sulphate solution, is used. The dispersive electrode is applied as previously outlined.

c. *Prescription*

Milliamperes—10 to 15 ma.
Voltage—Minimum
Polarity—Positive to active electrode.
Time—10 to 15 minutes according to area treated.
Frequency—Once every seven to ten days.

D. *Ion Transfer to Mucosal Surfaces*

1. *Application to Cervix*

a. *Medication* A copper, silver, or zinc sound as illustrated in Fig. 9, page 42.

b *Method* The patient is placed in the usual dorsal posture—the so called lithotomy posture—and the cervix brought into view by means of a speculum The vaginal vault and the external os of the cervix are thoroughly cleansed A copper sound of appropriate diameter is selected and introduced into the cervical canal

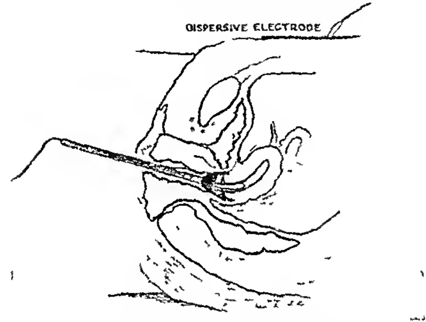

FIG 17 Illustration of the application of electrode for copper ion transfer to the cervix.

as far as the internal os The staff of the sound is connected to the positive terminal of the generator Fig 17.

The dispersive electrode may be placed under the sacrum, or on the abdomen, according to which application is the more comfortable and convenient When it is time to terminate the treatment, the current intensity should be reduced gradually to zero, and the polarity of the active electrode changed from positive to negative by reversing the polarity switch. Then increase the current intensity slowly to approximately 10 to 15 ma until the

electrode is loosened; then gradually reduce the current to zero, and remove the copper sound.

c. *Prescription*

Milliamperes—20 to 50.
Voltage—Minimum.
Polarity—Positive to copper sound.
Time—30 to 45 minutes.
Frequency—Every seven to ten days.

d. *References*

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2. Tovey, D. W.: Copper Ionization in the Treatment of Cervicitis. New York State J. Med. 30:887-889 (Aug. 1) 1930.
3. Tovey, D. W: Copper Ionization for the Treatment of Leucorrhea in Virgins. Am J Obst. & Gynec. 27:916-917 (June) 1934.
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2. *Application to Vagina*

a. *Introduction.* Sloan (1) states: "The great desideratum in pelvic ionic medication is an apparatus which will enable the ions to enter the tissues of the whole of the parts affected sufficiently deep to destroy the septic condition uniformly. . . . A septic condition more or less in degree generally exists throughout the whole genital tract in the great majority of pelvic troubles. The apparatus [illustrated in Fig. 18 and devised by Sloan] is efficient

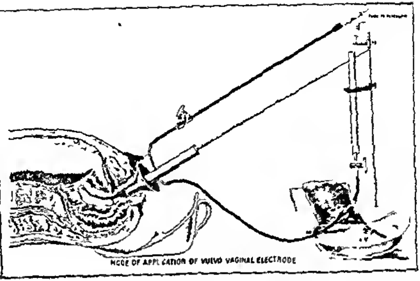

FIG 18 Application of vulvo vaginal electrode devised by Sloan (From Sloan, S Vulvo vaginal Electrode for Ionic Medication Proc Roy Soc Med Vol 2 Part 1, Electrotherapy Section, April 16, p 123, 1909)

and sufficiently under control so that the vagina and the uterus are ballooned by the solution. The walls are therefore stretched, all folds of mucous membrane are opened and gland orifices are exposed."

b *Medication* One per cent copper sulphate solution.

c. *Method* From Sloan (1, 2, 3, 4, and 5)

The patient is placed in the posterior position. The vaginal tract is thoroughly cleansed The funnel shaped electrode is inserted, and separated from the surface of the vagina and vulva by approximately four or five layers of gauze saturated in the copper sulphate solution. A reservoir, suspended about eight inches above the electrode, is connected by rubber tubing to the inlet tube of the electrode. The vaginal end of the inlet tube should be extended by a flexible rubber tube, three inches into the vagina, so that the solution will be carried well back into the vagina. The electrode is maintained in position and contact between electrode and tissue made water tight by means of constant pressure exerted by a retaining rod and spring The retaining rod is attached to a

burette stand, making an angle of about 20° to 30° with respect to the plane on which the patient lies. Fig. 18. The positive terminal is attached to the retaining rod to conduct the current into the solution.

A burette is attached to the stand as illustrated, and by means of rubber tubing connected to the outlet tube of the electrode. Suitable clamps are attached to both inlet and outlet rubber tubing to regulate the flow of the solution Before the current is turned on, a small quantity of fluid is run through the system to insure that all parts of the genital tract are free from discharge. The outlet clamp is then closed, and the solution permitted to distend the vagina. The vagina will usually retain from two to six ounces of the solution It is necessary to avoid distress from overdistention. The dispersive electrode is applied in the region of the sacrum, or abdomen if preferred The current is then turned on.

d. *Prescription*

Current—30 milliamperes for 10 minutes, or such current flow that the product of milliamperes and minutes equals 300.
Voltage—Minimum.
Polarity—Positive to vaginal electrode
Time—10 minutes, or such time that the product of time in minutes and milliamperes equals 300 ma.-minutes.
Frequency—Once every ten days.

e. *References*

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2. Sloan, S.: The Electro Chemical (Ionic) Treatment of Certain Gynecological Affections. Lancet 2: 1759 (Dec 23) 1911.
3. Sloan, S.: Ionic Medication in the Treatment of Some Obstinate Cases of Pelvic Disease in Women. Lancet 2:68 (July 10) 1909.
4. Sloan, S.: Therapeutics in Gynecology. Lancet 1:347 (Feb. 5) 1910.
5. Sloan, S.: Electrotherapy in Gynecology. Hoeber, Inc, New York. 1918.
6. Savill, A.: Treatment of Puritas Vulvae, Leucoplakia and Kraurosis. Brit. J. Dermat 52:321-338 (Nov.) 1940.

3 *Application to Maxillary Antrum*

a *Medication* One per cent zinc sulphate solution

b *Method* There are two methods

(1) *That employed by Campbell* The antrum is thoroughly cleansed The patient is placed on a treatment table in the prone position, with the forehead resting on a headrest, while the chest

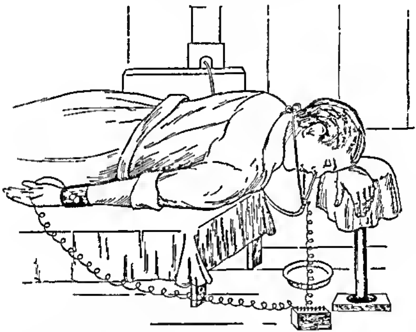

Fig 19a Illustrating the position of the patient for the application of zinc ion transfer to the antrum. (From Campbell A Ionization in the Nose, A New Technique Journal of Laryngology and Otology 43 98, Feb, 1928)

is at the edge of the table Fig 19a A space of about nine inches intervenes between the forehead and the upper part of the sternum The patient rests his head on his left forearm In this position, the anterior nares are at the lowest part of the nasal passages, while the posterior choana and the sphenoidal sinuses

are at their highest. An insulated metal tube is introduced into the nose through a plasticene plug placed in the nostril The plug of plasticene serves to center tube preventing contact with tissue, and also serves to prevent leakage of solution. An irrigating can is placed about a foot above the patient's head, and is connected

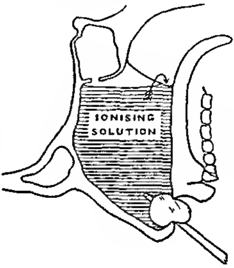

FIG 19b Schematic drawing illustrating the filling of the antrum with zinc sulphate solution and the continuous overflow of solution into the opposite nostril (From Campbell, A Ionization in the Nose; A New Technique. Journal of Laryngology and Otology 43 98, Feb, 1928)

to the catheter by means of rubber tubing The flow of zinc sulphate solution from the container is controlled by means of a screw clamp The solution is allowed to run into the nose so that it fills up one side and overflows continuously into the other, and escapes into a basin placed on the floor. Fig 19b. The positive terminal of the generator is connected to the metal tube. The current is turned on and gradually increased The maximum current employed is usually from 20 to 30 ma. The treatment is given for 20 to 30 minutes. The dispersive pad, prepared as usual, is applied to any convenient part of the body.

(2) *That employed by the authors.* This method was devised so that the patient could sit up during the treatment. A specially designed electrode, illustrated in Fig. 20, permits access directly into the antrum In Fig 20 three views of the electrode are given: side, top, and end.

Zinc sulphate solution is introduced into the antrum through the hollow electrode, a rubber hose conveying the solution from a suspended container to the electrode The flow is adjusted so that the antrum fills and the excess overflows continuously into the opposite nostril and escapes into a pan which is held by the patient

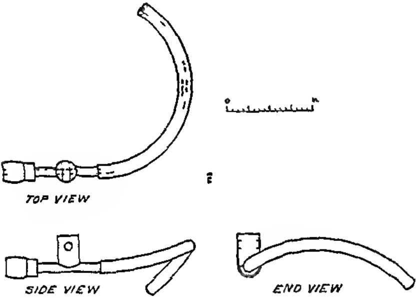

FIG 20 Electrode for zinc ion transfer to maxillary antrum Drawn to scale *Use of this electrode permits treatment of patient in the sitting position* The electrode is introduced into the antrum. The electrode consists of metal tubing with an external diameter of about 3/32 of an inch it is insulated by means of radio spaghetti as indicated in the figure Rubber tubing is connected to the electrode to convey zinc sulphate solution from a suspended container to the electrode and thence into the antrum

The positive terminal of the generator is connected to the electrode, and the current is gradually increased The maximum current employed is 20 to 30 ma as with the Campbell technic The time of application is also the same—20 to 30 minutes

c. *Prescription*

Milliamperes—20 to 30.
Polarity—Positive to antrum electrode.
Time—20 to 30 minutes.
Frequency—Every seven to ten days.

d. *Discussion*. Obviously, withnut adequate drainage of the various sinuses, it is not possible to use any method of ion transfer successfully. According to Cahill (3), treatment is useful chiefly in post-operative conditions After radical antrum and frontal sinus operations, ion transfer is of the greatest benefit in bringing about a speedy recovery. Zinc ion transfer is indicated after the removal of nasal polypi. It is also successful in clearing up post-influenzal rhinitis which does not involve the sinuses to any pronounced degree. Cahill used sodium chloride instead of zinc sulphate for the majority of pnst-nperative conditions.

4. *Application to Nares*

a *Medication*. One per cent zinc sulphate solution.

b. *Method*.

(1) Patient is given 3 grains of sodium amytal.
(2) After 15 minutes, the nasal cavity is packed with 5 per cent cocaine.
(3) Pack a roll of vaseline cotton into the olfactory fissure to prevent injury to the nerve with consequent loss of smell.
(4) Cleanse the nasal cavity with 1 per cent zinc sulphate solution.
(5) Pack the nose with half-inch strips of the thinnest available gauze, saturated with 1 per cent zinc sulphate solution, and place a zinc wire in the center of the pack to be connected to the positive terminal of the generator.
(6) Be sure to pack carefully beneatb both middle and lower turbinates.
(7) Be sure to pack far back into naso-pharynx. The patient is placed in the supine position, and the active electrode is connected to the positive terminal of the generator.

The patient lies on a suitably prepared dispersive electrode

c *Prescription*

Milliamperes—150 ma minutes

Note Milliampere minutes is the product of milliamperes and time in minutes In this instance, 15 ma for 10 minutes is the usual prescription, equivalent to 150 ma min, the same prescription could be administered at 10 ma for 15 minutes, or at any milliamperage which multiplied by the time of application gives 150 ma min It could be 10 ma for 15 minutes, and so on

Voltage—Minimum

Polarity—Positive to the active electrode

Time—10 minutes for 15 ma, or 150 ma minutes divided by ma used will give the time in minutes

Frequency—Every seven or ten days

d *Discussion* It is essential to follow closely the directions When the treatment is terminated, one should observe a greyish deposit over the nasal mucosa if the treatment has been adequate After three to four days, the membrane loosens and causes some annoyance to the patient, therefore, he should be cautioned not to use force in blowing his nose If much discomfort follows the treatment, ½ grain codeine with aspirin is usually administered

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4 Dean, L W The Fundamentals of Allergic Rhinitis with Particular Reference to Ionization Ann Otol Rhin & Laryng 45 326 338 (June) 1936

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10. Stout, P. S : The Value of Ionization in Nose, Throat and Ear Conditions. Med. World. 56·36-38 (Jan.) 1938.

5. *Application to the Ear*

a. *Medication.* One per cent zinc sulphate, or Friel's solution Friel's solution consists of 75 grains of zinc sulphate, 2 ounces of glycerine, and 17 ounces of water.

b. *Method.* Thoroughly mop the external meatus. Apply suction with a suction bulb, and then cleanse the ear further, using zinc sulphate solution for intratympanic irrigation. After draining the ear, instil an injection of ten minims of 2 per cent cocaine-adrenalin solution. This shrinks the mucosa and opens up pockets. Drain out cocaine solution, wash the tympanic area, and fill with zinc sulphate solution.

The patient lies with the affected ear uppermost, the solution filling the ear to the external meatus The glass speculum shown in Fig 21 is placed vertically in a beaker of zinc sulphate solution;

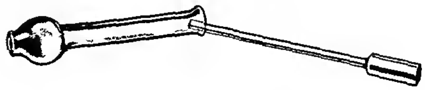

FIG 21 Glass speculum and zinc rod electrode used for zinc ion transfer to the middle ear

the opening of the speculum is covered with a finger, so that when the speculum is removed from the solution an adequate amount of solution will be retained in the bulb of the glass tube The glass speculum is placed in the external meatus and so inserted that its direction parallels the ear canal Fig 22 The finger is then removed The zinc rod electrode is connected to the positive

FIG 22 Application of the active electrode illustrated in Fig 21 for zinc ion transfer to the middle ear

terminal and placed in the glass speculum It is imperative at all times to have good contact between the zinc rod and the solution in the glass speculum The electrode should be held securely in the ear by the patient or by someone in attendance

Since the patient is lying down the dispersive electrode can be readily positioned under the palmer surface of the hand and adequate pressure for good contact can be provided by sandbags placed on the back of the hand

c *Prescription*

Milliamperes—Never exceed 3 ma
Voltage—Minimum

Polarity—Positive to the ear electrode

Time—Usually 10 minutes, or longer, depending upon milliamperage employed The product of ma and minutes should be 30 ma -minutes

Frequency—Once every seven to ten days

d *Discussion* The treatment is limited to certain simple uncomplicated cases which have large central perforations Good results cannot be expected in conditions where there are only minute central or peripheral perforations

e *References*

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4 Friel, A R Notes on Chronic Otorrhoea, With Special Reference to the Use of Zinc Ionization in the Treatment of Selected Cases William Wood & Company, Baltimore, 1929
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6 Persky, A H Chronic Suppurative Otitis Media Arch 54 425 433 (July) 1937
7 Wells, Arthur G The Treatment of Chronic Suppurative Otitis Media The Practitioner 148 334 1942

E *Specific Polar Applications*

1 *Application for Inflammation of Peripheral Nerves*

a *Medication* None Positive electrode is usually employed for its alleged sedative effect However, Turrell believes either pole is equally effective

b *Methods*

(1) *Application to Lower Extremity*

(a) Active Electrode Applied to foot and lower third of leg

An absorbent electrode of cellucotton, asbestos paper, or canton flannel, saturated in a 1 per cent hot saline solution, is applied in good contact with the foot and lower third of the affected leg A plate of metal foil is applied over the absorbent material covering the sole of the foot, and connected to the pole selected. Its position is maintained with a rubber bandage.

(b) *Dispersive Electrode* A well-moistened dispersive pad electrode, 6 by 8 inches, is applied over the sacroiliac region, and connected to the other terminal.

(2) *Applied Directly Over the Affected Nerve*

(a) *The Active Electrode* The patient is placed in the prone position A strip of cellucotton or asbestos paper, of sufficient width and length to cover completely the affected nerve region, is saturated in a 1 per cent hot saline solution and placed over the region to be treated A metal electrode, slightly smaller in area than the cellucotton, is applied over the cellucotton and connected to the positive terminal The electrode is maintained in position by sandbags or by a rubber bandage.

(b) *The Dispersive Electrode* Prepared and applied as previously described.

(3) *Application to the Upper Extremity*

(a) *Active Electrode* The affected arm is placed in a small arm bath The saline solution, at a comfortable temperature, covers the forearm A strip of metal is immersed in the bath and connected to the positive terminal of the generator.

(b) *Dispersive Electrode.* A dispersive pad, 6 by 8 inches, prepared as previously described, is applied to the region of the cervical and upper dorsal spine, and connected to the negative terminal

(4) *Labile Applications* (Active electrode in motion)

(a) *Active Electrode.* Use either a metal roller electrode with a chamois covering, or a so-called "hand electrode," both of which are illustrated in Fig 9, page 43 These so-called "labile" applications are so named from the fact that the active electrode is kept continuously in motion by the technician The electrode

is saturated in a 1 per cent hot saline solution, and is connected *to the positive terminal. The electrode is moved slowly over the* involved area. The current intensity is maintained at the patient's tolerance.

(b) *Dispersive Electrode.* The patient is placed in the most comfortable position. A 6 by 8 inch dispersive electrode, prepared as previously described, is applied to some convenient area of the patient's trunk and connected to the negative terminal.

(c) *Prescription* (Methods 1, 2, 3, and 4).
Milliamperes—Tolerance.
Voltage—Minimum.
Polarity—Positive or negative according to choice.
Time—40 to 45 minutes
Frequency—Daily, or 2 to 3 times weekly.

(d) *Discussion:* It is assumed that the underlying causes of the pathologies have been ascertained and the necessary steps taken to correct them. A large proportion of the conditions, arising from such simple causes as exposure to dampness and cold, are relieved in about ten to twelve treatments. While corrective procedures are being applied, this form of adjuvant therapy can be most useful. It is often merely palliative, and thus does not remove the cause of the condition. Turrell believes patients are relieved as the result of the heat produced by the conversion of electrical energy into heat energy in the tissues This was explained in Experiment 11.

(e) *References*

1. Turrell, W. J.: Principles of Electrotherapy and Their Practical Application. 2nd Ed Oxford University Press, New York 1929.
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F. *Electrical Testing of Nerves and Muscles.* The complete neurological examination to determine the extent or degree of a nerve lesion, is not within the province of the physical therapist

but belongs to the field of the neurologist However, the physical therapist and the technician should be sufficiently familiar with neurological pathologies and the diagnostic procedures and terminology of the neurologist to realize the full significance of the diagnosis made of the patient and the purpose of the recommended treatment Moreover, he should have the ability to determine the electrical excitability of a pathological nerve and its associated muscles By such tests the result of treatment may be followed from week to week

The most commonly employed currents for muscle and nerve testing are the direct and the tetanizing or faradic current However, condenser discharge currents are being used to an increasing extent

1 *The Normol Nerve and Muscle Response*

a *Direct Current* The direct current, when allowed to flow without interruption through a nerve or muscle, does not cause muscular contraction If the circuit is suddenly opened or closed by means of a suitable key, and if the current is of sufficient strength contraction occurs at the make and at the break of the circuit If a nerve is stimulated, all of the muscles supplied by it will contract, but if the electrode is placed over the motor point of an individual muscle, that muscle alone will respond If the current is very strong contiguous muscles may also contract The pole used as the exciting electrode is of importance In the case of the normal nerve or muscle, the negative pole or cathode is more effective in producing stimulation than is the positive pole hence with it, a minimal contraction is secured with the least current intensity The positive pole or anode, for the same degree of muscle contraction requires a greater current intensity This gives rise to the so called *normal polor formula* for muscle contraction that is for a given current intensity *the cathodal closing contraction is greater than the onodal closing contraction,* or CCC > ACC > AOC > COC Stimulation of a normal motor nerve or muscle causes a sharp quick, lightning like contraction

The reaction of the patient with spasmophilia is an exception to the normal polar formula The motor nerves of such patients

show a marked degree of hyper-irritability. The direct current provides a positive test for the early detection of this condition. The test is positive when the cathodal opening contraction (COC) is secured with a current of less than 5 ma.

For practical reasons, opening contractions are very infrequently used, since the current intensity required to produce them exceeds the patient's tolerance.

b. *Tetanizing or Faradic Current.* The faradic current of sufficient intensity produces a complete tetanic contraction of the muscles during its flow; the contraction does not terminate until the current flow ceases. This current produces a series of rapid stimulations, and hence the tetanic response. This is discussed in detail in Part B.

2. *Electrical Reactions Resulting From Lower Motor Neuron Lesions.* The abnormal electrical responses resulting from an injury to a lower motor neuron are known as the *Reaction of Degeneration*, abbreviated *R.D.* or *DeR.* This has been defined by Erb to be an entire cycle of quantitative and qualitative changes of irritability, which occurs in the nerves and muscles under certain pathological conditions and is associated ultimately with certain histological degenerative changes occurring in these structures.

Nerve disorders may be classified as:

a. *Organic*

(1) Anatomical, in which the anatomical continuity of the nerve is broken.

(2) Physiological block, in which the anatomical continuity of the nerve remains intact but its ability to conduct impulses is impaired because of long sustained pressure on the nerve somewhere along its course.

b. *Functional*

(1) Hysteria

(2) Feigned paralysis, or Malingering.

A muscle deprived of its nerve supply will not respond to faradic

stimulation Hence, the faradic current can be of great assistance in differentiating between an organic lesion and a functional disorder.

The direct current will stimulate a muscle to contract whether the muscle is normal or paralyzed, provided the muscle fibers have not been replaced by fibrous tissue. The paralyzed muscle responds, however, with a slow, sluggish, so-called longitudinal or vermicular reaction, instead of the quick, lightning-like contraction characteristic of the normal muscle

Table 11 gives the electrical responses secured when the reaction of degeneration is complete.

TABLE 11

ELECTRICAL REACTIONS SECURED WHEN PARALYSIS OF A NERVE AND ITS MUSCLES IS COMPLETE

Current	Nerve	Muscles
Faradic	No Response	No Response
Direct	No response because there is no nerve path below the injury to conduct the stimulus	1 *Qualitative* May be (1) slow or (2) slowed or (3) sluggish 2 *Quantitative* May require from 15 to 50 ma. before a response can be elicited. 3. *Polar Formula* May be (1) Normal CCC>ACC (2) Equal CCC=ACC (3) Reversed CCC<ACC

The polar reversal was considered by Erb of great prognostic significance, but at present this view is wholly unsupported.

3 *Technic*

a *General.* A good light is necessary to avoid confusing and misleading shadows The patient must be comfortable and relaxed If possible, precede the test with some form of heat to reduce the electrical resistance of the skin to a minimum

b. *Electrodes.*

(1) *Active* A small, circular metal electrode, covered with absorbent material, as illustrated in Fig 23 It is attached to a handle equipped with a make-and-break key Fig 9, page 42

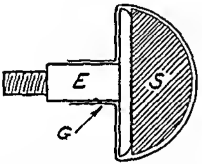


FIG 23 Electrode for electro-diagnosis A circular metal electrode E, about ½ to ¾ inch in diameter, is covered with an absorbent material S This absorbent material, which may be cellucotton or sponge, is covered and held in place by gauze

(2) *Dispersive.* An electrode, 4 by 6 inches, is applied to the back, chest, or other convenient area.

c. *Current*

(1) *Faradic.* The method employed for the test depends on the extent of the lesion If the nerve supplying the paralyzed muscles is in a location where it can be stimulated, the nerve trunk on the normal side is first stimulated by briskly and continuously opening and closing the muscle testing electrode to find the normal faradic current threshold The threshold is obtained when the muscle contracts with the minimal current intensity If the nerve trunk cannot be stimulated because of its location, then the normal muscle opposite to the one paralyzed is stimulated

at its motor point to find the normal current threshold The motor point is situated where the nerve enters the muscle and is usually located at about the geometric center of the muscle Fig 24 Without changing the machine settings, the muscle testing electrode is applied to the nerve (if possible) and to each of the muscles at their motor points If no response is secured, the current is increased gradually to the absolute tolerance of the patient In complete reaction of degeneration neither the muscle nor its nerve will respond to the faradic stimulus

(2) *Direct* The same procedure as outlined above is employed Even with complete reaction of degeneration, unless the injury is very old the muscles will respond to the direct current The responses should be noted and recorded

In early cases of paralysis, the muscles can be most easily stimulated at their motor points Fig 24, pp 89 95, but with the passage of time, the muscle becomes less and less irritable until in the course of time, if regeneration of the nerve has not occurred response to the direct current will be totally lost If a muscle does not respond to a stimulus applied at its motor point, the electrode should be moved gradually toward the tendinous insertion of the muscle until the *point of election* is found When the current is applied at this point, the muscle may respond The fingers should be placed over the tendons of the muscles being tested to detect slight movements that otherwise might go unnoticed The spread of current to contiguous muscles must be noted and if it occurs, guard against misinterpreting these spurious contractions

Change of varying degree may be noted in the responses of the muscle to the direct current

(a) *The qualitative response* The muscle contraction may be slow, slowed, or sluggish (vermicular contraction)

(b) *The quantitative response* A much greater current intensity may be required to produce a threshold contraction

(c) *The polar formula* The formula may be

Normal, i e CCC $>$ ACC, or
Equal i e CCC $=$ ACC, or
Reversed, i e CCC $<$ ACC

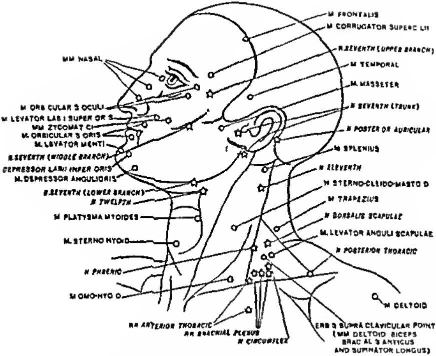


Fig 24A Motor Points of the Face and Neck. (From Electro-Diagnosis Courtesy of J M Mosher)

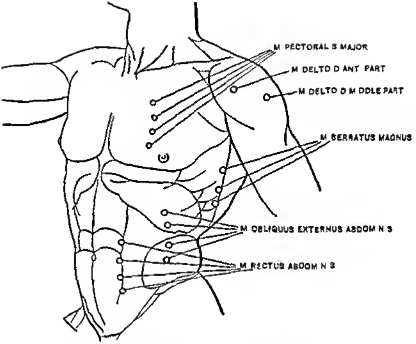


FIG 24B Motor Po nts of the Trunk Anterior Surface (From Electro-Diagnosis Courtesy of J M Mosher)

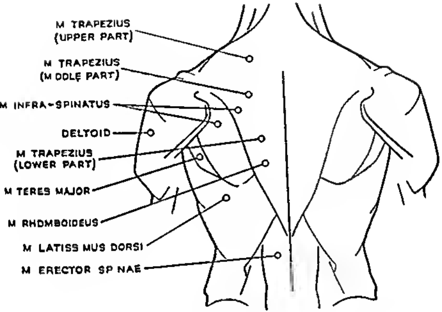


FIG 24C Motor Points of the Trunk Posterior Surface (From Electro-Diagnosis Courtesy of J M Mosher)

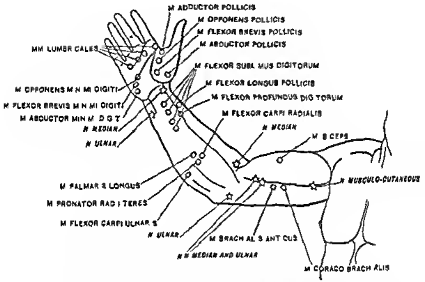


FIG 24D Motor Points of the Arm and Hand, Flexor Surfaces (From Electro-Diagnosis Courtesy of J M Mosher)

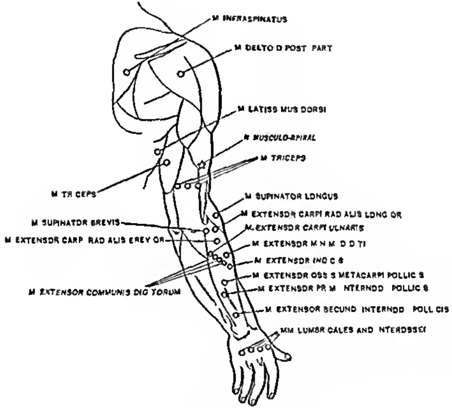


FIG 24E. Motor Points of the Arm and Hand Extensor Surfaces (From Electro Diagnosis Courtesy of J M Mosher)

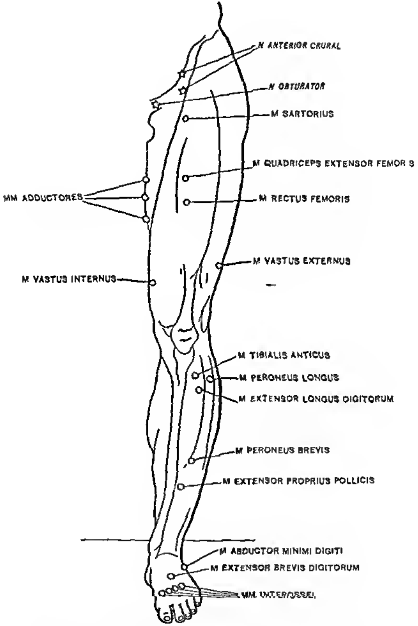


Fig 24F Motor Points of the Thigh and Leg, Anterior Surface (From Electro Diagnosis Courtesy of J M Mosher)

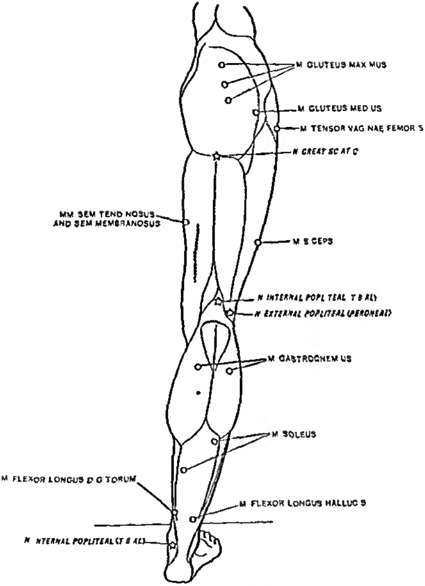


FIG 24G Motor Points of the Thigh and Leg Posterior Surface (From Electro-Diagnosis Courtesy of J M Mosher)

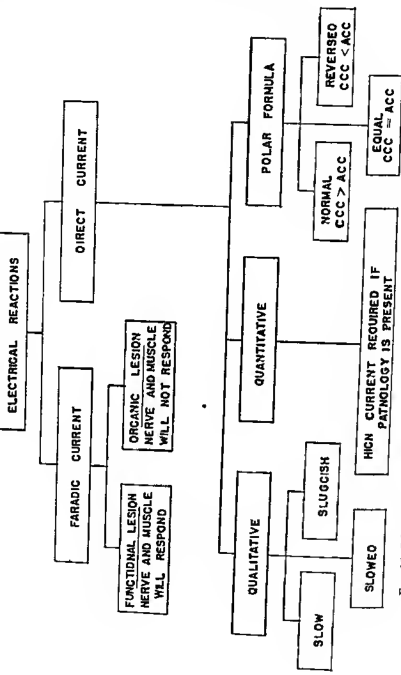


Fig 25 Schematic outline of the procedure for the determination of Reaction of Degeneration

SUGGESTED RECORD FORM FOR ELECTRICAL EXAMINATION OF NERVE AND MUSCLES FOR REACTION OF DEGENERATION

Nerve	Faradic Current	Direct Current
Radial	No Response	No Response

Muscle	Faradic Current	Direct Current	Ma for Minimal contraction		Polar Formula	Type
			Cathode	Anode		
Triceps	Reduced	Slowed	10	15	CCC>ACC	Normal
Brachio radialis	No Response	Sluggish	50	30	CCC<ACC	Reversed
Supinator brevis	No Response	Sluggish	30	30	CCC=ACC	Equal
Extensor carpi radialis	No Response	Sluggish	45	25	CCC<ACC	Reversed
Extensor carpi ulnaris	No Response	Sluggish	30	30	CCC=ACC	Equal
Extensor communis digitorum	No Response	Sluggish	50	50	CCC=ACC	Equal
Extensor indicis proprius	No Response	Sluggish	30	40	CCC>ACC	Normal
Extensor brevis pollicis	No Response	Sluggish	30	20	CCC<ACC	Reversed
Extensor longus pollicis	No Response	Sluggish	35	50	CCC>ACC	Normal
Extensor minimi digiti	No Response	Sluggish	40	30	CCC>ACC	Reversed

In Fig 25 is outlined the procedure for determining the reaction of degeneration

Students interested in the condenser method of muscle testing should consult Kovacs, *Electro therapy and Light Therapy*

4 *References*

1 Erb, W H Handbook of Electrotherapeutics William Wood & Company, Baltimore, 1883
2 Athanassio Benisty, Marie Clinical Forms of Nerve Lesions Oxford University Press, New York, 1918
3 Pollock, L J and Davis L Peripheral Nerve Injuries Paul B Hoeber, Inc, New York, 1933
4 Bauwens P Electro diagnosis and Electrotherapy in Peripheral Nerve Lesions Proc Roy Soc Med 34 459 468 (June) 1941

G *Electrolysis* (so called *Surgical Ionization*)

1 *Uses*

a Destruction of tissue in such conditions as

(1) Nevus araneus
(2) Telangiectasis
(3) Acne rosacea
(4) Hypertrichosis
(5) Common mole
(6) Nevus pilosus, when hair is dark and coarse

2 *Principle* The destruction results from the chemical action of the ions liberated by the current The advantage of this method is that the destruction is definitely localized and always under control The resultant scars are minimal and very pliable, giving excellent cosmetic results

3 *Technics*

a *Hypertrichosis*

(1) *Active Electrode* The active electrode consists of a platinum irridium needle with a bulbous end It is fixed in a suitable holder and connected to the negative pole

(2) *Dispersive Electrode* A 4 by 6 inch dispersive pad is placed as previously described, and connected to the positive pole

The skin is cleansed with alcohol The needle is sterilized in alcohol *The patient is placed in the supine position and a small* sheet of rubber is placed over the clothing, covering his chest A dispersive pad, with moist absorbent surface uppermost, is placed on the rubber sheet and connected to the positive terminal The area of operation is exposed, and well illuminated, so that the opening of the follicle is readily visible To accomplish this, direct the light so that it falls on the skin in a direction approximately parallel to the hair at its exit from the follicle

The needle is inserted into the hair follicle, making sure that the needle follows the direction of the hair It can usually be inserted about one eighth of an inch before the tip of the needle reaches the bottom of the hair follicle The patient is instructed to place his hand on the dispersive electrode, the operator increases the current until an intensity of 2 milliamperes is reached The current should never be excessive, experience has indicated that it should not exceed 2 milliamperes By using a low current intensity, pain is minimized and extensive tissue destruction with resultant scar formation is prevented There is a sharp, stinging pain when the needle is inserted into the follicle, but it is not so severe that an anesthetic is necessary The current is allowed to flow for about 15 seconds or until slight effervescence is seen at the mouth of the follicle The patient is then told to remove his hand from the dispersive pad The hand thus serves as a switch The needle is not withdrawn until the hand is removed from the dispersive pad and the circuit thus interrupted The hair is seized by an epilation forceps and removed—but not unless it can be done with ease It should come out without the slightest effort on the part of the operator If it does not come out readily, the needle should be reinserted and further electrolysis effected The procedure outlined is repeated for each hair to be removed When a large number of hairs is to be removed no more than from twenty to thirty should be removed at a single sitting, and these should not all be removed from the same area If an appreciable number were removed from a restricted area, the minute liquified follicles might coalesce and form a large scar The successful use of this method requires both practice

and skill Under the best conditions a certain number of hairs (about 20 per cent) return and must be removed again For the removal of fine hairs, a finer needle, a weaker current, and greater skill are required Fine downy hairs cannot be removed satisfactorily by electrolysis If they lie very close together and electrolysis is attempted, scarring is liable to result

It is important that the needle be inserted into the hair follicle without piercing the wall of the follicle It has been found that holding the hair in a forceps facilitates the proper insertion of the needle otherwise it might pierce the side of the follicle

b *Other Pathologies*

In treating *stellate veins*, the needle is introduced for about one eighth of an inch into the central vein from which the others radiate One milliampere is passed for one minute A minute scab forms which drops off in a few days leaving a tiny scar which later becomes unnoticeable

Acne rosacea may be treated so as to save overlying skin and produce minimum scarring If the skin contains capillary nevi some scarring is unavoidable

Electrolysis is a useful procedure in the treatment of nevi composed of separated vessels stellate veins, telangiectases in adults and minute capillary nevi For large capillary nevi, excision or freezing with carbon dioxide is to be preferred Positive current is also effective for raised mole like nevi (*nevus varicosis*)

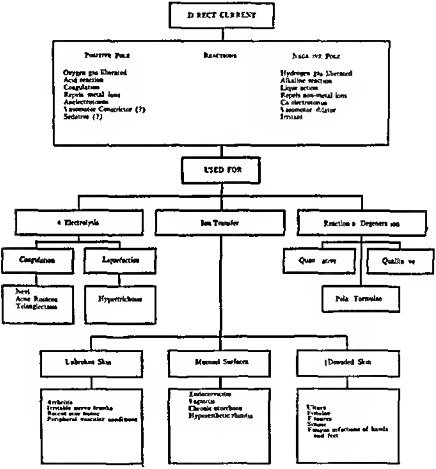
c *Prescription*

Milliamperes—1 to 2
Voltage—Minimum
Polarity—Negative to the platinum iridium needle, bulbous for hypertrichosis and sharp for other applications Positive to needle for nevus varicosis
Time—15 to 30 seconds

d *Apparatus Required*

1 Direct current generator
2 Dispersive electrode, 4 by 6 inches

H Summary of Direct Current Reactions and Applications



3 Suitable needle holder for holding platinum iridium needle
4 Adjustable light source of good intensity
5 Epilation forceps
6 Magnifying lens

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7 Cumberbatch E P Essentials of Medical Electricity 8th Ed. Sherwood Press Cleveland, 1939
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PART B MUSCLE STIMULATION BY ELECTRIC CURRENTS

SECTION ONE GENERAL CONSIDERATIONS

I INTRODUCTION The experiments of Galvani demonstrated that muscles contract when subjected to an electrical potential These experiments marked the beginning of electro-physiology From that time on, electric currents have been employed for stimulation of muscles, both for experimental and therapeutic purposes

Contributions of the greatest importance in electro physiology were made by Emil du Bois Reymond (1818 1896) In 1884, he published a comprehensive work *Thierische Electricitat* The du Bois Reymond induction coil for electro muscle stimulation was devised by him in 1849 He also introduced a special make and break key, known as the ***du Bois Reymond key*** Du Bois

Reymond was the first to describe electrotonus, and to him we are indebted for our modern concepts of summation of response and of prolonged contractions. His basic work led to the elucidation of the *law of excitation* by Pfluger Du Bois-Reymond experimentally proved that a constant current had no effect upon a nerve, but that muscular contractions occur only when there is a change in the applied potential. He also discovered the *negative variation*, or as it is now called, the *action current*, associated with muscular activity.

The value of and the rationale for the use of electrical stimulation in the treatment of denervated muscle are disputed points. Most clinical physical therapists, on the basis of "clinical experience," advocate its use However, the value of such impressions gained from experience on human subjects is questionable It is practically impossible to conduct a controlled study of this problem in man. Evidence derived from studies on experimental animals is contradictory. Many of these studies base their conclusions upon an insufficient number of experiments, inadequately controlled However, the conclusions reached from several well controlled studies are about equally divided for and against the value of electrical muscle stimulation Some of this evidence will be considered in detail

Reid[1] in 1841 cut the spinal motor roots supplying the hind legs in four frogs He stimulated the same side daily for two months with direct current and found that the muscles on the treated side retained their original size and contractility, whereas those of the opposite side atrophied markedly and contracted only feebly. However, Langley[2] has shown that denervated frog muscle does not atrophy. Many workers since have failed to find any change in the excitability or contractility of denervated amphibian muscle. Brown-Sequard[3] cut the sciatic nerves bilaterally in rabbits and stimulated one leg for six weeks. At the end of this time the muscles on the stimulated side were normal, whereas those on the

[1] Reid, J · Edinburgh Month. Journal Med Sci (1841) Quoted by Langley and Hashimoto J Physiol 52·15, 1918

[2] Langley, J N J Physiol. 50 335, 1916

[3] Brown Sequard Compt Rend des Seances et Med d l Soc de Biol 195 (1849) Quoted by Langley and Hashimoto, J. Physiol 52·15, 1918

uostimulated side showed marked atrophy, and their ahility to contract to a stimulus was greatly decreased.

Langley and Kato[4] studied the course of atrophy in the gastrocnemius soleus group of the rabbit. The effect of electrical stimulation for four minutes daily was studied io seven animals. The results apparently showed that electric stimulation with condenser discharges delayed atrophy. However, the number of experiments was few, the differences slight, and no adequate controls were included Hence the results, as the authors themselves stated, are inconclusive. Langley cut the internal and external popliteal nerve bilaterally io one rabhit. He stimulated one side two or three times each day with coodeoser discbarges at the rate of thirty-six per minute. A total of two and one-half bours of stimulation was given daily. In this way, by using prolonged and vigorous stimulation, he hoped to draw cooclusioos as to whether deoervation atrophy actually was due to disuse. However, he found no difference in the weights of the treated and control muscles after twenty-ooe days

In 1920, Hartman and Blatz[5] studied the effect of massage, aod electrical treatmeot on denervated rabbit muscle. They appear to be among the few investigators who employed a functiooal rather than an aoatomical test for compariog the muscles. The work which the muscle was capahle of doing wheo lifting an optimum load was used as a staodard for comparisoo. The gastrocnemius muscle on one side of a bilaterally sciatic sectioned animal was treated daily with direct current stimulation. Twenty-four animals were studied. These investigators produced contractions which varied io different animals from a harely perceptible response to a vigorous response. The muscle was stimulated ten minutes daily at the rate of sixty stimuli per minute They reported no beneficial effects and stated that denervatioo was followed in a few days by the loss of power to contract to galvanic stimulation in both treated and control groups. In view of this statement, it is difficult to understand how their method of electric stimulation produced contractions except during the first days of the experiment.

[4] Langley, J N, Kato, T. J Physiol 49·432, 1915
[5] Hartman, F. A., Blatz, W E J Physiol 53 290, 1920

Recently, interest in this problem has been revived Probably the best study is that of Fischer[6] He appears to be the first experimental investigator to attempt to adapt the form of electrical stimulation to the changing excitability of the denervated muscle *so as to produce vigorous contractions throughout the course of* the experiment By varying the frequency and duration of the stimulus, he was able to produce a tetanic contraction in markedly atrophic muscle From a well controlled study on rats he concluded that electrical stimulation retards loss of excitability and loss of relative dry weight of the stimulated muscles The best results were obtained when treatment was started *immediately* after denervation Fischer stimulated the muscles from ten to twenty minutes daily, using a current intensity sufficient to produce a vigorous contraction

In 1939, Chor, Cleveland, Davenport, Dolkert, and Beard[7,8] studied the effect of various procedures, including electrotherapy, on the atrophy of denervated muscle in the monkey They concluded that electrotherapy was of no value in delaying or preventing atrophy, *or in hastening muscle-nerve regeneration* They employed direct current stimulation, producing ten contractions daily Their experiments were made principally on unilaterally denervated animals This study appears to have been inadequately controlled, for they did not consider variations in the rate of atrophy from animal to animal, neither did they state the number of animals used Both Fischer[9] and Langley and Hashimoto[10] have shown that this variation could be considerable In contrast to Fischer, they secured the best results when treatment was initiated four weeks after denervation

More recently Molander, Sternitz, and Asher[11] cut the sciatic nerves bilaterally in eleven dogs One leg was stimulated with direct current, twice daily, five contractions at each session After

[6] Fischer E Am J Physiol 127 605 1939

[7] Chor H. Cleveland D Davenport H A Dolkert R. E and Beard G J A.M A. 113 1029 1939

[8] Chor H. Cleveland D Davenport H A Dolkert R E and Beard G Physiol Review 19 340 1939

[9] Fischer E Am. J Physiol 127 605 1939

[10] Langley J N Hashimoto M J Physiol 52 15 1918

[11] Molander C O Sternitz F S and Asher R. Arch Phys Therapy 22 154 1941

six weeks, the corresponding muscles were removed and weighed. The treated muscles showed as much weight loss as did the controls. However, in six of the nine cases, the control muscles showed slightly more histologic evidence of degeneration. They concluded that electrotherapy was of no value.

On the other hand, Kowarschik and Nemec,[12] using a special stimulating apparatus for obtaining a current of optimal form, state that electric stimulation is of value in preventing atrophy and restoring muscle function.

Very recently, Liebesny[13] employed an interrupted direct current with variable frequency and pause, termed by him a Leduc current. In an experiment on one frog he showed that this current was less fatiguing than the usual interrupted direct current. In one rabbit with paralyzed hind legs, he treated one leg with the so-called Leduc current, and the other leg with the direct current for ten minutes daily, giving 240 contractions. He stated that the direct current was of no value but that the Leduc current was of marked value. These results are suggestive, but the small number of experiments and lack of adequate controls do not justify far-reaching conclusions. Liebesny states that he has used the Leduc stimulation in 134 poliomyelitis patients and 1000 peripheral nerve injuries with very satisfactory results.

Gutmann and Guttmann[14] crushed or cut the peroneal nerve, bilaterally, in six rabbits They stimulated one leg with the direct current daily for fifteen to twenty minutes, securing 500 to 600 contractions, using the other leg as a control They concluded that electrical stimulation not only delayed and diminished muscular atrophy but also accelerated the return of the muscle to its initial volume Moreover, the treated muscles exhibited greater electrical excitability than did the controls Since their controls did not include the normal variations from animal to animal, their results are not fully conclusive. However, if the controls of Langley and Hashimoto[15] are applied to these experiments, then the results of Gutmann and Guttmann seem to be significant.

[12] Kowarschik, J , Nemec, H Munschen Med Wchnschr 88 269, 1941
[13] Liebesny, P: Arch Phys Therapy 23 23, 1942
[14] Gutmann, E , Guttmann, L· Lancet 1:169, 1942
[15] Langley, J N , Hashimoto, M.· J Physiol 52·15, 1918

Solandt and Magladery[16] have reported that stimulation for two minutes, three times daily, with a twenty-five cycle sinusoidal current, considerably decreased atrophy in denervated rat muscle The number of animals used is not stated

The most recent work is that of Hines, Thomson, and Lazere,[17] published in 1943 These investigators concluded that electrical stimulation of paralyzed muscles, if of sufficient intensity to induce strong contractions, delays atrophy and enhances recovery from paralysis

It is thus apparent that there is no agreement in the experimental literature as to the value of electrical muscle stimulation However, there are certain general observations which can be made In general, when daily treatment is given, when the periods of stimulation are relatively long, and when the current strength is sufficient to cause a vigorous muscle contraction, the results are favorable The single exception to this generalization is based on the results obtained in an experiment on a single animal Without exception, those who employed weak stimuli or short periods of stimulation have reported unfavorable results Again, those who have attempted to adapt their stimuli to the changing excitability of the degenerating muscle have had better results In spite of this, a recent clinical article[18] advocates the use of weak stimuli, insufficient in intensity to produce joint movement The basis for this recommendation is not clear

From a consideration of the physiology involved, it would appear logical that if a muscle is to be electrically stimulated, the resultant contraction should simulate as nearly as possible the normal muscle contraction The following discussion is based on this point of view

II MUSCLES CAPABLE OF BEING ELECTRICALLY STIMULATED All muscles can be electrically stimulated, but some, because of their anatomical location, are inaccessible for such stimulation Muscles capable of being electrically stimulated may be classi-

[16] Solandt, D Y, Magladery, J W Brain 63 255 1940

[17] Hines, H. M, Thomson, J D, and Lazere, B Physiologic Basis for Treatment of Paralyzed Muscle Arch. Phys Therapy 24 69, 1943

[18] Snow, W B, Gurewitsch, A B Arch Phys Therapy 23 69, 1942

fied as: skeletal muscle with intact nerve supply; skeletal muscle deprived of its nerve supply (the paralyzed muscle); and the smooth or involuntary muscle.

A. *Skeletal Muscle with Intact Nerve Supply:* The normal skeletal muscle contraction is tetanic in character. According to Piper such a contraction is produced by stimuli entering the muscle at the rate of 40 to 120 per second. As can be readily demonstrated, these stimuli must all occur within a limited phase of the contraction cycle in order that a tetanic contraction be produced; hence the individual stimulus must necessarily be of short duration.

1. *Electrophysiology*

a. *Chronaxie:* Muscle is a highly irritable tissue, and its degree of irritability can be determined by electrical stimulation.

When we speak of the electrical excitability of muscle, we immediately encounter difficulties. If electrodes are applied directly to a muscle with intact innervation, the muscle is not stimulated directly but indirectly through its nerve. Hence unless curarization or single fiber preparations are used, or latent period measurements are taken, it is probable that most so-called direct stimulation of muscle actually is indirect stimulation.

The response of an irritable tissue, such as muscle and nerve, to an electrical stimulus depends upon several factors: one, the form of the current, that is, its rate of rise; two, the current intensity; and three, the duration of current flow. Each of these factors has been employed to study electrical excitability of muscle.

Lapicque has shown that all irritable tissues, whether normal or pathologic, have a reasonably constant threshold intensity, or rheobase, for the direct (galvanic) current. The time, however, that the threshold current must flow to produce a contraction varies widely with different tissues.

Arbitrarily Lapicque doubled the experimental threshold current intensity in order to arrive at an intensity which would be adequate. Keeping this new current value constant, he measured the remaining variable—that is, the time this current must flow

to excite the muscle under study. The duration time thus obtained Lapicque called the *chronaxie* of the muscle. Fig. 26. He established the fact that the normal skeletal muscle has a very short chronaxie, ranging from about .001 to .005 second

Chronaxie has been used clinically as a measure of excitability

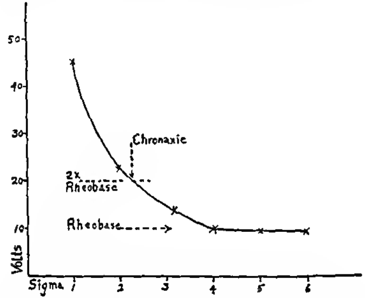

FIG 26 Diagram illustrating excitation time, rheobase, and chronaxie. (From Wiggers, Carl J Physiology in Health and Disease, 2nd Edition Lea and Febiger, Philadelphia, 1927.)

for the study of denervated muscle. Lapicque's critics have made it necessary to modify markedly Lapicque's original concept of chronaxie. For example, it has been found that chronaxie will vary with such factors as size of electrodes, position of electrodes, and distance between electrodes.

Lucas[19] and Rushton[20, 21] have shown that at least two distinct strength-duration curves can he obtained from muscle under certain experimental conditions, the so-called alpha and gamma excitability. They have identified the alpha curve with muscle,

[19] Lucas, K · J Physiol. 36.113, 1907
[20] Rushton, W A. H · J Physiol 74 424, 1932
[21] Rushton, W. A. H. J Physiol 75 161.445, 1932

and the gamma curve with nerve. They also believe they are able to demonstrate a third or beta curve which they associate with the neuromuscular junction. The muscle curve is characterized by a chronaxie ten to one hundred times that of its motor nerve. It is interesting to note, however, that the rheobase value

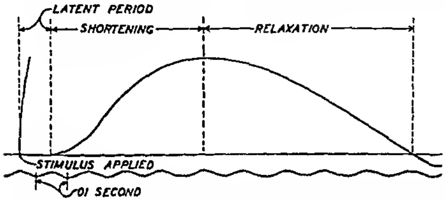

FIG. 27 A single contraction of a frog muscle produced by a single electric stimulus (From Carlson and Johnson The Machinery of the Body University of Chicago Press, Chicago, 1937)

is less for muscle than for nerve Theoretically, it is predictable, according to Blair[22] that a lengthening of chronaxie will be accompanied by a decreased rheobase unless a change in threshold occurs Hence, a slowing of excitabilty in the ordinary sense (i e, lengthening of chronaxie) is accompanied by a lowered rheobase. This means a decreased irritability to currents of short duration and an increased irritability to currents of long duration These relationships are apparent in the alpba and gamma curves of muscle. It is apparent in the strength-duration curves of muscles at different temperatures Lapicque originally denied the existence of the alpha curve but later reversed his opinion. He[23, 24] still denies, however, that the alpba curve is a true strength-duration curve, and states that chronaxies measured on it are false chronaxies.

b *The Single Stimulus:* When a muscle is stimulated with a

[22] Blair, H A Biological Symposia Muscle 3 51, 1941
[23] Lapicque, L. J Physiol. 73 189, 1931
[24] Lapicque, L J Physiol 76 621, 1932

single stimulus, the well known kymographic tracing of the resultant muscle contraction, shown in Fig 27, is obtained The complete curve of muscle contraction consists of 3 phases the latent period, or the interval between the application of the stimulus and the beginning of contraction, the period of contraction, or shortening of the muscle, and the period of relaxation, or elongation of the muscle

c *The Summation of Stimuli* When a series of successive stimuli is applied to a muscle, an effect is produced which will vary according to the rapidity with which these stimuli follow each other If the interval following each stimulus be sufficiently long to enable the muscle to recover from the effects of the preceding stimulus there will be no change in the form or character of the contraction following each stimulus except for a slight increased irritability of the muscle during the early part of the contraction phase

If however, a second stimulus is applied to a muscle during the period of contraction or early in the period of relaxation, a second contraction occurs, which is superimposed on the first, and the resultant contraction will be greater than that produced by either stimulus alone Experiment has shown that the greatest effect of a second stimulus is produced when the stimulus is applied during the last third of the shortening phase of the contracting muscle The summation, or resultant, of the two component contractions is almost twice as great as that produced by the single stimulus The effect on muscular contraction of repeated properly timed stimuli is known as the effect of *summation of stimuli* Fig 28 It has been demonstrated that normal muscle cannot attain its maximum shortening except through a summation of repeated stimuli (40 to 120 per second)

d *The "All or None Theory"* The *all or none theory* of muscle contraction postulates that if a single muscle fiber is stimulated a maximum shortening or none at all of that fiber is obtained The degree to which a muscle contracts depends on the total number of fibers of that muscle which have been stimulated The rate of contraction is determined by the rate at which successive muscle fibers are stimulated If all the fibers are simultaneously stimulated, the contraction will be abrupt and shocklike But if

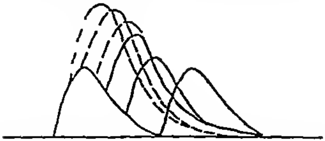

FIG 28 Diagram illustrating the summation of two contractions in different phases of contraction and relaxation. (From Wiggers, Carl J.: Physiology in Health and Disease, 2nd Edition Lea and Febiger, Philadelphia, 1937.)

the fibers are progressively stimulated, the resultant contraction will be graduated, progressively increasing in degree until all the fibers have been stimulated This type of contraction simulates the normal contraction.

2. *Electric Current Most Effective for Stimulating Normal Skeletal Muscle*

Graduated contraction of normal skeletal muscle should theoretically be secured best by means of a surging interrupted direct current with alternate polarity Such a current is illustrated in Fig. 29. To conform with the *all-or-none theory*, the current should surge gradually to a maximum intensity, so that the muscle fibers will be progressively stimulated to secure the desired degree of muscle contraction. During each surge of the current cycle, which corresponds to the phase of muscle contraction and relaxation, the current should be interrupted in such a manner as to simulate the impulses which enter the normal skeletal muscle during volitional effort. Since, according to Piper, the number of impulses should range between 40 and 120 per second, the rate of interruption of the current should be within this range.

With each surge of such a current, the muscle under stimulation will contract and relax. Each surge of current should be followed by a period of rest, i e., a period of no current flow. The ratio of the duration of current flow to that of no current flow should probably be two to one, as indicated in Fig. 29.

To neutralize undesirable electrolytic effects due to an appreciable current intensity, which may persist for as long as six

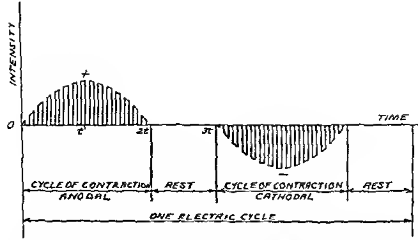

Fig 29 The theoretical current best suited for the stimulation of skeletal muscle with intact nerve supply The Surging Interrupted Direct Current with Alternate Polarity The interruptions are from 40 to 120 per second The frequency of surge ranges from 5 to 100 per minute Each current surge is followed by a period during which no current flows (rest period) The ratio of the time of the surge of current to the time no current is flowing is about 2 to 1 A complete cycle of variation consists of two surges of opposite polarity with their associated isoelectric periods as illustrated

seconds, the polarity of the current at the completion of the contraction cycle is reversed. The current follows the same wave contour, completing the second half of the electrical cycle.

The number of muscular contractions it is desired to secure per minute will vary. This variation is dependent on the functional condition of the muscle. The frequency of the induced contraction cycle should range from five to one hundred per minute This corresponds to an electric cycle frequency of 2½ to 50 per minute, or a surge frequency of 5 to 100 per minute. Such range of frequency should be adequate for all clinical requirements.

A contraction will be obtained for each alternation of current, i e , one for the positive or anodal phase, and one for the negative or cathodal phase of the cycle. The magnitudes of the contractions will not necessarily be the same, but will be in strict accord with the polar formula of the individual In the case of the normal skeletal muscle, the contraction obtained with the negative or cathodal phase of the current will be greater than that obtained

with the anodal phase, and the magnitudes of the anodal and cathodal contractions will be in agreement with the polar formula.

The original surging interrupted current, which is modified as described to produce a current theoretically best adapted for stimulation of normal skeletal muscle, may be sinusoidal in wave form, which means that the amplitude follows a definite law known as the sine law. Such a term, however, should not be applied to a current unless the current definitely follows this law. The terms "slow sinusoidal" and "rapid sinusoidal" have been used as if they designated two distinct types of current, producing quite different physiologic effects. The usage of such terms is unfortunate and confusing Obviously these terms should be used with discrimination The term "slow" or "rapid" refers merely to the number of alternations per minute, each alternation producing one muscular contraction. The term relates only to the speed of contraction, which may be fast or slow, according to the physiologic activity of the muscle under stimulation.

When stimulating muscles with an electric current, it is necessary to regulate the number of current alternations per minute and thereby the number of muscle contractions per minute. The rate of the induced contractions should be regulated to be in accord with the physiologic activity of the muscle.

It is evident that it is extremely difficult to apply an accurately descriptive term to the current described, and illustrated in Fig. 29. Probably the term *Surging Interrupted Direct Current with Alternate Polarity* describes the current with sufficient accuracy to impart a clear concept of the current referred to. Such a current as we have described should stimulate a normal skeletal muscle to a maximum contraction with a minimum current intensity.

B. *Skeletal Muscle Deprived of Its Nerve Supply. (The Paralyzed Muscle.)*

1. *Electrophysiology*

There are two diametrically opposed views as to the cause of atrophy in denervated muscle: one, that atrophy results from disuse, and the other, that it results from exhaustion. The theory for atrophy of disuse is supported by two types of evidence:

First According to Tower,[25] [26] muscles which have an intact nerve supply but which are functionally inactive because of immobilization in plaster, tenotomy, or isolation of the efferent innervation from all afferent stimuli, will undergo atrophy

Second Contraction of denervated muscle either by passive motion or by active contraction produced by electrical stimulation will, according to Fischer,[27] Solandt and Magladery,[28] Kowarschik and Nemec[29] and Gutmann and Guttmann,[30] prevent or delay atrophy

That denervation atrophy is simply a disuse atrophy, however, is contradicted by the following evidence

First The atrophy of denervation, and the atrophy of disuse, although grossly indistinguishable, are histologically different, this fact indicates that the two processes are related but, according to Tower,[31] not identical

Second Actually, denervated muscle is not at rest but is in a state of continuous, fine, irregular fibrillation Functionally inactive muscle with intact innervation does not fibrillate This fibrillation *was first described by Schiff,[32] in 1851*, and has more recently been studied by Solandt and Magladery,[33] Langley and Kato,[34] and Hayes and Woolsey[35] Langley[36] and Hartman and

[25] Tower S S Trophic Control of Non Nervous Tissues by Nervous Systems Study of Muscle and Bone Innervation From Isolated and Quiescent Region of Spinal Cord J Comp Neurol 67 241 (Aug) 1937

[26] Tower S S Reaction of Muscle of Denervation Physiol Rev 19 (Jan) 1939

[27] Fischer E Effect of Faradic and Galvanic Stimulation Upon Course of Atrophy in Denervated Skeletal Muscles Am J Physiol 127 605 (Nov) 1939

[28] Solandt D Y Magladery J W Relation of Atrophy to Fibrillation in Denervated Muscle Brain 63 255 (Sept) 1940

[29] Kowarschik J Nemec H Fortschritte der elektrischen Lahmungsbehandlung Munchen med Wchnschr 88 269 (March 7) 1941

[30] Gutmann Ernest Guttmann Ludwig Effect of Electrotherapy on Denervated Muscles in Rabbits Lancet 1 169 (Feb 7) 1942

[31] Tower S S Reaction of Muscle to Denervation Physiol Rev 19 (Jan) 1939

[32] Schiff M Arch f Physiol Heilkunde 10 579 665 1851

[33] Solandt D Y Magladery J W Relation of Atrophy to Fibrillation in Denervated Muscle Brain 63 255 (Sept) 1940

[34] Langley J N, Kato T The Rate of Loss of Weight in Skeletal Muscle

Blatz,[37] failing to demonstrate any beneficial effect from passive motion or electrical stimulation suggested that denervation atrophy is fatigue atrophy resulting from continuous fibrillation Tower,[31] who in 1939 reviewed the literature, also supported the fatigue theory of atrophy The evidence which may be cited in support of this view is as follows

One Langley[38] has shown that denervated frog muscle does not fibrillate, neither does it atrophy

Two According to Langley and Itagaki[39] and Knowlton and Hines,[40] the oxygen consumption of denervated muscle is greater than that of normal muscle

Three Levine, Hechter, and Soskin[41] stated that the biochemical changes accompanying atrophy are those characteristic of fatigue

Four In the denervated gastrocnemius muscle of the rat, Levine, Goodfriend, and Soskin[42] found that prostigmine increased fibrillation and also increased the rate of atrophy, whereas atropine, which diminished fibrillation decreased the rate of atrophy markedly Their results, however, are not in agreement with

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After Nerve Sections With Some Observations on the Effect of Stimulation and Other Treatment. J *Physiol* 49 432 1915

[35] Hayes G J Woolsey C N The Unit of Fibrillary Activity and the Site of Origin of Fibrillary Contractions in Denervated Striated Muscle Fed. Proc. Fed Am Soc Biol 1 Part 2 pp 38 (March 16) 1942

[36] Langley J N *Observations on Denervated Muscle* J Physiol 50 335 (July) 1916

[37] Hartman F A Blatz W E Studies in the Regeneration of Denervated Mammalian Muscle III Effects of Massage and Electrical Treatment J Physiol. 53 290 1919 20

[38] Langley J N P Observations on Denervated Muscle J Physiol 50 335 (July) 1916

[39] Langley J N Itagaki M The *Oxygen Use of Denervated Muscle* J Physiol 51 202 1917

[40] Knowlton G C Hines H M Respiratory Metabolism of Atrophic *Muscle Am J Physiol 109 200 (Aug) 1934*

[41] Levine R Hechter O and Soskin S *Biochemical Characteristics of* Denervated Skeletal Muscle at Rest and After Direct Stimulation Am J Physiol 132 326 (March) 1941

[42] Levine R. Goodfriend J Soskin S Influence of Prostigmin Atropine and Other Substances on Fibrillation and Atrophy in Denervated Skeletal Muscle of Rat Am. J Physiol. 135 747 (Feb) 1942

those of Solandt and Magladery,[43] who stopped fibrillation with quinine and failed to observe any decrease in the rate of atrophy.

Five The time of onset of fibrillation coincides with the beginning of atrophy and the biochemical changes of fatigue.

If denervation atrophy is due to exhaustion, the contraction of muscle by electrical stimulation certainly appears to be contraindicated However, it is possible that electrical stimulation may be of value in other ways than in the production of contraction; it may decrease or abolish fibrillation or it may increase blood flow through the muscle and improve its nutrition. The work of Solandt and Magladery[44] and Hartman and Blatz[45] would seem to indicate that electrical stimulation has little or no effect on the fibrillation of denervated muscle As far as we know, no one has studied the effects of stimulation per se (i e, independent of contraction) on actual blood flow.

A muscle deprived of its nerve supply shows the *Reaction of Degeneration.* Such a muscle exhibits a slow, sluggish contraction —a contraction quite similar to that of the normal involuntary or smooth muscle Clinical experience has demonstrated to us that the current we have found effective for stimulating paralyzed muscle is just as effective for stimulating smooth or involuntary muscle On the contrary, this current is not adapted to the stimulation of normal skeletal muscle Hence, one might conclude that there is a similarity between the electrophysiology of paralyzed muscle and smooth, or involuntary, muscle so far as electric stimulation is concerned Therefore, we shall consider the stimulation of paralyzed muscle in comparison with the effect of electric currents in exciting contraction in smooth muscle

a. *Chronaxie* At present no well controlled study of the strength-duration curve throughout the course of atrophy has been presented The available evidence, however, indicates that

[43] Solandt, D Y, Magladery, J W Relation of Atrophy to Fibrillation in Denervated Muscle Brain 63 255 (Sept) 1940

[44] Solandt, D Y, Magladery, J W Relation of Atrophy to Fibrillation in Denervated Muscle Brain 63 255 (Sept) 1940

[45] Hartman, F A, and Blatz, W E Studies in the Regeneration of Denervated Mammalian Muscle III Effects of Massage and Electrical Treatment J Physiol 53 290, 1919-'20

the short chronaxie of a normal muscle is abruptly replaced, without preliminary modification, by a lengthened chronaxie 10 to 100 times the normal [46] It is possible, therefore, that the lengthened chronaxie, which appears rather suddenly, represents the true muscle excitability of Lucas and Rushton The research of Rosenbleuth and Dempsey[47] supports this concept Rosenbleuth reports that no change occurs in the chronaxie of nerve during the first four days following section, but after the first four days, neuromuscular transmission suddenly ceases Reports do not agree on the rheobase changes occurring in denervated muscles Theoretically, one would expect a decrease

A less well known method of evaluating muscle excitability is to determine the current intensity and the time at which the threshold contraction occurs for currents increasing linearly at different rates This method of studying muscle excitability has been extensively employed by Lucas,[48] Fabre,[49] and Blair [50] Its employment as a diagnostic test in peripheral nerve injuries has recently been suggested by Bauwens [51] [52]

A third method of studying electrical excitability is the determination of the strength frequency function This has been studied extensively on normal muscle and nerve by A V Hill,[53] Acheles,[54] Lullies,[55] Coppee [56] Koch[57] and Katz [58] It would appear that this type of test has a more direct bearing on the choice of current for stimulation than any other Yet it has not been applied clinically as far as we know That the three tests are all

[46] Langley J N J Physiol 50 335 1916
[47] Rosenbleuth A Dempsey E W Am J Physiol 128 19 1939
[48] *Lucas K J Physiol 36 253 1907*
[49] Fabre P C R Acad Sci Paris 184 699 1486 1927
[50] Blair H. A Am J Physiol 3 515 1935
[51] Bauwens P Proc Roy Soc Med (London) 34 459 1941
[52] Bauwens P Brit. J Phys Med 4 150 1941
[53] Hill A V Katz B and Solandt D Y Proc Roy Soc Med (London) B 121 74 1936
[54] Acheles J Arch ges Physiol (Pflugers) 224 217 1930
[55] Lullies H Arch. f d. ges Physiol 225 98 1930
[56] Coppeé G Cold Spring Harbor Symposia 4 150 1936
[57] Koch H. Renqoist Y Skandinav Arch of Physiol 59 266 278 1930
[58] Katz B J Physiol 96 202 1939

interrelated and depend upon the three basic factors in electric excitation will become obvious upon closer examination Thus a change io the frequency of a sine wave stimulus involves

One A change in the rate of rise of the individual pulse, aod

Two A change in the duration of each pulse

There is no standard method for the expression and comparison of excitability Perhaps the most familiar clinical test is that of Erb, which measures galvanic and faradic excitability. Others have employed chronaxie measurements Recently Moor[59] and Watkins[60] have studied the entire strength-duration or voltage-capacity curves Hill,[61, 62, 63] Monnier,[64] Blair,[65, 66] and Rashevsky[67] have presented some theoretical treatments of electrical excitability which allow the latter to be expressed in fairly quantitative terms bearing some theoretical and perhaps practical significance These theories all are basically very similar and are founded on simple principles which make no attempt to explain the actual physical or biologic nature of the process, but simply allow existing excitability data to be treated quantitatively.

The *chronaxie* of a paralyzed muscle, like that of a smooth muscle, is from 20 to 100 times as long as that of a skeletal muscle with an intact nerve supply. A tetanizing (faradic) current which has a relatively high frequency of alternation fails to stimulate a paralyzed or smooth muscle, because the duration of current flow is too short

b *The Single Stimulus:* The kymographic tracing of the contraction of a paralyzed skeletal muscle resulting from a single stimulus, like the contraction of a smooth or involuntary muscle, is similar to that of the normal skeletal muscle shown in Fig 27,

[59] Moor, F B, Dail, C W, and Kellogg, K Arch Phys Therapy 21 396, 1940

[60] Watkins, A L Arch Phys Therapy 21 76, 1942

[61] Hill, A V, Katz, B, and Solandt, D Y Proc Roy Soc Med (London) B 121 74, 1936

[62] Hill, A V Proc Roy Soc Med London B 119 305, 1936

[63] Hill A V Proc Roy Soc Med London B 119 440, 1936

[64] Monnier, A M L'Excitation Electrique des Tissue Hermann Paris, 1934

[65] Blair, H A Am J Physiol 3 515, 1935

[66] Blair, H A Cold Spring Harbor Symposia 4 63, 1936

[67] Rashevsky, N Cold Spring Harbor Symposia 4 90, 1936

except that each of the three phases, namely, latent, contraction, and relaxation, is proportionately lengthened

c. *The Summation of Stimuli:* In the case of smooth muscle and paralyzed muscle, there is no summation of stimuli as previously described for normal skeletal muscle. Such muscles apparently contract as the result of a single stimulus. To secure repeated contractions, the stimulus is repeated from 10 to 20 times per minute.

d *The "All-or-None" Theory:* This theory holds for the stimulation of the fibers of paralyzed and smooth muscles, just as it does for the stimulation of normal skeletal muscles

2. *Electric Current Best Suited for Stimulation of a Muscle Deprived of Its Nerve Supply.*

The intensity of the current used for stimulation of paralyzed muscles should be gradually increased to the desired maximum and then gradually decreased to zero This variation provides a single stimulus The succeeding stimulus should consist of a similar current variation but of opposite polarity. Such a *Surging Uninterrupted Direct Current with Alternate Polarity* is illustrated in Fig 30

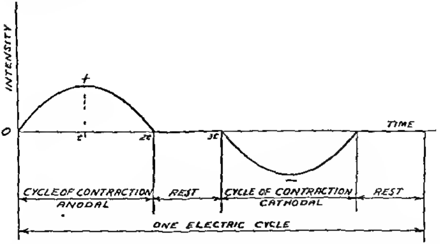

Fig 30 The theoretical current best suited for the stimulation of a muscle without nerve supply The Surging Uninterrupted Direct Current with Alternate Polarity Surge frequency, 10 to 20 per minute Each surge of current is followed by a rest period The ratio of the time of the surge of current to the time no current is flowing is about 2 to 1

The current should be perfectly smooth and devoid of all interruptions The duration of each surge that has been found effective ranges from 3 to 6 seconds Each surge of current is followed by a period of rest or of no current flow, as indicated in Fig 30 The maximum or peak intensity of the current should be such as will secure the desired contraction The effectiveness of this type of current may be due to the fact that in each cycle

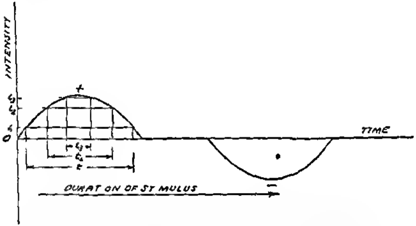

FIG 31 Diagram showing that in each surge of current represented in Fig 30 there are current flows of appropriate duration and of sufficient intensity to secure full contraction of a muscle with impaired nerve supply

there are current flows of appropriate duration and of sufficient intensity to secure full contraction of the muscle Fig 31 On the other hand the effectiveness of an electric current in eliciting a response in a denervated muscle may be due to the rate of rise of the current and its duration of flow For the normal muscle, A V Hill has shown that an instantaneous rise is best for stimulation (See Fig 29, page 114)

The number of induced muscle contractions per minute must not be greater than that which will permit complete relaxation of the muscle between the application of successive stimuli Since the response of paralyzed muscle is sluggish, the number of contractions induced per minute should be few, therefore, the term "slow sinusoidal current has frequently been used to designate the

type of current which produces the desired number of contractions per minute without regard to whether it follows the sine law. Such a current is more accurately described as a *Surging Uninterrupted Direct Current with Alternate Polarity*. The frequency of this alternating current should be sufficiently low, and the rest period sufficiently long, to assure complete relaxation of the muscle between successive contractions.

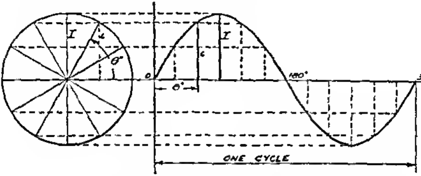

FIG. 32. A sinusoidal current. Instantaneous current i equals maximum or peak current I times the sine of the angle Θ, or $i = I \sin \Theta$

A true sinusoidal current follows a definite mathematical variation. The amplitude of such a current is directly proportional to the sine of an angle, being zero at 0°, a positive maximum at 90°, zero at 180°, a negative maximum at 270°, and zero at 360°. This variation constitutes a complete cycle. Such an alternating current is depicted in Fig. 32. The value of the current at any instant equals the maximum, or peak, value multiplied by the sine of the angle. In Fig. 32, let us assume that the current has a maximum value of 10 milliamperes. The instantaneous value of the current, θ degrees after the beginning of the cycle, is 10 times the sine of θ°. If θ is 60°, the instantaneous value is 10 times the sine of 60° or 10 times 0.866 or 8.66 milliamperes

The current used for the stimulation of muscles may or may not follow the sine law. Only when such currents follow this law should they be designated sinusoidal currents. In fact, few currents used for muscle stimulation follow this law, and there is no evidence that they should. It may be that the wave form of

the ideal current for the stimulation of paralyzed muscles should approximate that of the curve of muscle contraction.

C. *Smooth or Involuntary Muscle.* It has been claimed, although without conclusive proof, that peristalsis of the intestinal tract can be directly induced by electrical stimulation The *surging uninterrupted direct current with alternate polarity,* described above, is used for this purpose. Whenever any smooth or involuntary muscle is to be stimulated, this current should be used

III SUMMARY The types of current fully adequate and most desirable in clinical practice for the electrical stimulation of muscles are, in our opinion:

A *The Surging Interrupted Direct Current with Alternate Polarity,* having a surge frequency of 5 to 100 per minute and being interrupted from 40 to 120 times per second Fig 29

B *The Surging Uninterrupted Direct Current with Alternate Polarity,* having a surge frequency of from 5 to 20 per minute Fig 30

PART B MUSCLE STIMULATION BY ELECTRIC CURRENTS

SECTION TWO TYPES OF APPARATUS IN USE

I Introduction Muscles can be stimulated more or less effectively by electric currents having characteristics differing somewhat from those described in Section One as being ideal The following classification and nomenclature of the currents in present use, based on application, is suggested in an endeavor to clarify the present chaotic terminology

A *Skeletal Muscles with Intact Nerve Supply*

1 *Tetanizing (Faradic) Current*

a *Interrupted*

(1) Manually

(2) Mechanically

b *Surged*

(1) Manually

(2) Mechanically

2 *Direct (Galvanic) Current*

a *Interrupted*

(1) Manually

(2) Mechanically

b *Surging Interrupted Direct Current with Constant Polarity*

c *Surging Interrupted Direct Current with Alternate Polarity*

B *Skeletal Muscles Without Nerve Supply (Paralyzed Muscles)*

1 *Direct Current*

a *Interrupted*

(1) Manually

(2) Mechanically

b *Surging Uninterrupted Direct Current with Constant Polarity*

c *Surging Uninterrupted Direct Current with Alternate Polarity*

II DISCUSSION OF COMMONLY EMPLOYED MUSCLE STIMULATING CURRENTS CLASSIFIED ACCORDING TO THEIR USE

A *For Skeletal Muscle with Intact Nerve Supply*

1 *Tetanizing or Faradic Current* A *tetanizing* (faradic) current is an alternating current either symmetrical or unsymmetrical of relatively high frequency which on continuous application to a muscle produces a tetanic contraction of the muscle Fig 33 It has been the practice to secure such a current from the secondary of an induction coil employing some type of interrupter in the primary circuit such as the *Bristow* coil and the *Morton Smart* apparatus Equally effective tetanizing currents can be obtained by other means Hereafter all currents producing tetanic contraction regardless of the manner in which they are generated will be designated as *tetanizing* currents

To secure repeated contractions with intervals of rest the current must be either interrupted or surged

a *Interrupted* (1) Manually The standard muscle stimulating electrode equipped with a make and break key is employed for this purpose The electrode is applied to the motor point of the muscle to be stimulated with the dispersive electrode applied to some convenient part of the body and connected to the remaining patient terminal By opening and closing the circuit repeated contractions of the desired frequency are obtained

b *Surged* (1) Manually The iron core is rhythmically moved in and out of the coil by the operator s free hand while

Graph of faradic current

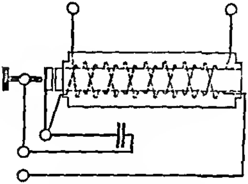

Diagram of faradic or induction coil

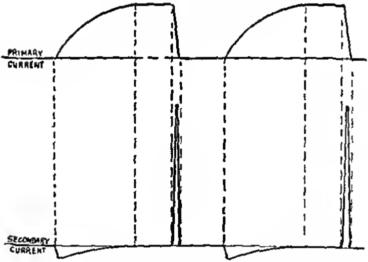

Diagram showing direction of current in primary and secondary induction coil at the make and break

FIG 33 Diagram of a tetanizing or faradic current as obtained from an induction coil (From Kovacs, Richard Electrotherapy and Light Therapy, 4th Edition Lea and Febiger, Philadelphia, 1942)

the active electrode is held in place on the muscles to be stimulated. The current intensity is thus gradually varied, increasing it to a maximum and then decreasing it gradually to zero The motion should not be abrupt, but uniform. Fig. 34.

(2) Mechanically Various types of current controlling devices are employed to produce automatically, without manual

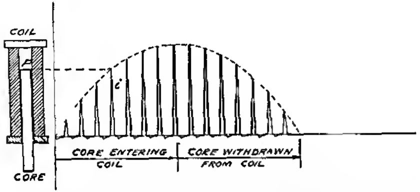

FIG 34 Diagram of a manually surged tetanizing or faradic current The contour, which is determined by the peaks of the secondary current, will depend on the uniformity and the rate at which the core of the induction coil is moved

manipulation, a surging tetanizing or faradic current Typical devices of this nature are:

(a) *The "Wall Plate":* The various devices employed for the generation, control, and automatic surging of a faradic current are frequently mounted on a panel or "plate" of insulating material, designed to be mounted permanently on a wall, hence the term "wall plate" to designate such an assembly Fig 35. The so called wall plate requires a source of direct current, and is usually employed only when there is available a direct current lighting circuit. Such units are provided also with appropriate potentiometers, rheostats, and meters, whereby a direct current may be made available, controlled, and measured Other devices on the plate are an induction coil to provide a faradic current and some type of current interrupter, together with an automatically varied resistance, to control the surge of the current. Such plates

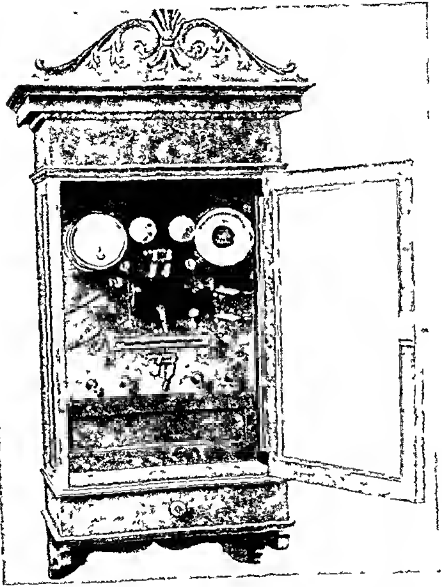

FIG 35 The so-called "Wall Plate," now replaced by more modern types of generators

provide a direct current, an interrupted direct current, a surging direct current, a so-called faradic current, an interrupted faradic current, and a surging faradic current

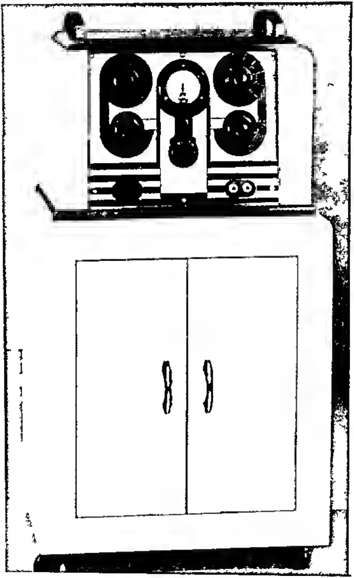

FIG 36 Representative modern generator of currents for muscle stimulation

(b) *Modern wave generators.* Such generators, designed for operation on the ordinary lighting circuit, provide means whereby the current received from the supply lines may be converted into rhythmically surged faradic currents, in addition to means for producing various other types of currents for electric muscle stimulation and direct current applications The frequency of surge can usually be varied from about 5 to 100 per minute. The contour wave usually approximates a sine wave Some of these generators employ motor-generator sets, and others vacuum tube circuits with requisite auxiliary devices for producing the desired currents. The Sine-O-Tron, illustrated in Fig 36, is representative of this type of generator Such equipment bas largely replaced the so called "wall-plate" and the manually operated induction coils

2. *Direct (Galvanic) Current* · Such a current is obtained from a direct current generator or from a radio "B" battery (Part A — Direct Current, page 4)

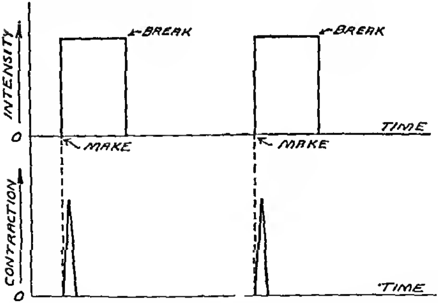

FIG 37 Schematic diagram of the interrupted direct current and the muscle contraction induced at the establishment, or *make* of the current. Contraction is sharp, shock like, and unsustained No contraction usually occurs at the opening or *break* of the circuit for the current intensity ordinarily employed

a *Interrupted*· (1) Manually. A standard active electrode, equipped with a manually operated make-and-break key, is connected to the appropriate terminal of the generator and applied to the muscle, with dispersive electrode properly applied and connected With an adequate current intensity, the muscle contracts each time the key is closed. The contraction is sharp and shock-like, single and unsustained, and does not simulate the normal, voluntary muscle action Fig 37. (2) Mechanically. The current is interrupted by means of a rheotome or some such automatic interruptor.

b *Surging Interrupted Direct Current with Constant Polarity:* The frequency of surge to be used will depend on the physiologic activity of the muscle to be stimulated; this may range from approximately 5 to 100 per minute. The interruptions of the current should be from 40 to 120 per second This type of current can be used whenever definite polar effects are desired in addition to the muscular contraction It may be schematically represented as shown in Fig 38

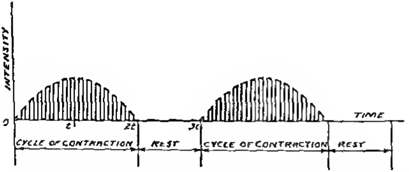

FIG 38 Surging Interrupted Direct Current with Constant Polarity The rate of interruption is 40 to 120 per second, and the number of surges 5 to 100 per minute A complete muscle contraction is obtained with each surge This current is used when polar effects are desired in addition to contraction

c *Surging Interrupted Direct Current with Alternate Polarity.* The frequency of surge and the frequency of interruption of the current should be as described in the preceding paragraph. This

current was described fully in Section One, page 113 Also see Fig. 29, page 114

Devices for the electrical stimulation of muscles frequently provide a current such as that shown in Fig 39. This current can be described as a modulated alternating current. The frequency of the alternating current is relatively high, usually a multiple of 60, the most common being 240, 360, and 420 cycles per second The frequency of the modulating wave is such that contractions of from 5 to 100 per minute are obtained. The form of the modulating wave is usually flat-topped, producing a modulated current of the "dwell-type" shown in Fig 39

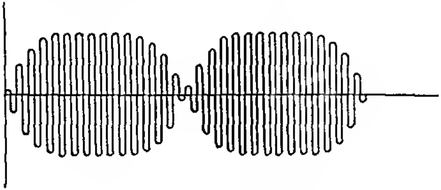

Fig 39 A modulated alternating current.

The rate of alternation of this current is too rapid to comply with physiological requirements. There is no evidence available for the use of such a current Moreover, during a recent investigation, conducted at Northwestern University Medical School, of various types of currents for the stimulation of muscles, observations were made which indicated that such a current might produce injurious effects (Unpublisbed data)

B. *For Skeletal Muscles Deprived of Their Nerve Supply (Paralyzed Muscles)*

As previously stated, such muscles contract with a slow, sluggish, wormlike (vermicular) contraction Their chronaxie is long

The current best suited to stimulate paralyzed muscles is devoid of interruptions it should be perfectly smooth and gradual in its variation in intensity A tetanizing or so called faradic current, having rapid or abrupt changes in current intensity, cannot be used for stimulating paralyzed muscles Electric currents most frequently employed for this purpose are

1 *Direct (Galvanic) Current*

a *Interrupted* (1) Manually, as previously described Fig 37 For reasons already presented, the shock like stimulus imparted by this current to a paralyzed muscle would not seem desirable (2) Mechanically by means of a rheotome or some such mechanical interrupter as already described A mechanically interrupted direct current is no more desirable from the viewpoint of the type of contraction obtained than is a manually interrupted direct current

b *Surging Uninterrupted Direct Current with Constant Polarity* Such a current is used when polar effects are desirable in addition to muscular contraction Furthermore, a current of this type may be indicated when a muscle shows a polar reversal (CCC < ACC), for such a muscle can be stimulated with less current if the active electrode remains positive throughout the entire application This current is represented schematically in Fig 40

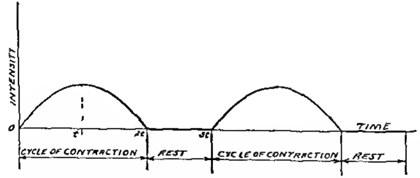

Fig 40 Surging Uninterrupted Direct Current with Constant Polarity (Negative or positive as required)

c. *Surging Uninterrupted Direct Current with Alternate Polarity (So-called Slow Sinusoidal Current):* The rationale for the use of this current has already been discussed, Section One, page 121. See also Fig 30. This current, according to our experience, approaches the ideal current for stimulating paralyzed muscles. The frequency of surge to be employed depends on the rate at which the muscle passes through a complete contraction cycle; it lies within the probable range of 5 to 20 per minute.

III. Essential Currents for the Electrical Stimulation of Muscles

A. *Direct Current*

B. *Tetanizing or Faradic Current.* Section Two, Fig. 33.

C. *Surging Uninterrupted Direct Current with Constant Polarity.* Section Two, Fig. 40

D. *Surging Uninterrupted Direct Current with Alternate Polarity.* Section One, Fig. 30.

E. *Surging Interrupted Direct Current with Constant Polarity.* Section Two, Fig. 38.

F. *Surging Interrupted Direct Current with Alternate Polarity* Section One, Fig 29.

IV. Experiment—(To be performed by the student under the supervision of an instructor)

Muscular Reactions to the Uninterrupted and the Interrupted Surging Direct Current With Alternate Polarity

Object:

1. To demonstrate by iontophoresis the polarity reversal of the current.
2. To demonstrate the difference in muscular contraction induced by an uninterrupted and by an interrupted surging direct current with alternate polarity.

Apparatus

1 Generator of muscle stimulating currents
2 Several good grade white blotters
3 A solution of 20 per cent potassium iodide
4 Two chamois covered metal hand electrodes
5 Two wood spring clothesline clips

Procedure

1 Saturate a blotter with potassium iodide Connect two conducting cords to the output terminals of the generator Select a surging direct current with reversal of polarity following each surge Be sure the milliammeter is connected for high current reading (0 to 150 ma), and that the *cord terminals are not brought in direct contact,* because a short circuit produced in this manner *might ruin the meter* With the terminals of the conducting cords held by the wood clothesline clips for insulation, draw the tips of both terminals slowly down the blotting paper with uniform speed, describing parallel paths Use sufficiently high current to obtain the liberation of iodine Plot to scale on cross section paper the resulting graph, which will be similar to that shown in Fig 41

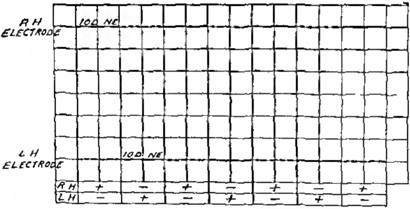

FIG 41 Demonstration of polarity reversal by the liberation of iodine during the positive phase Solid lines indicate brown stain of the liberated iodine at the positive electrode The dotted line represents the liberation of potassium at the negative electrode which produces no discoloration

2. Connect the two chamois-covered metal hand electrodes to the terminals of the conducting cords, having previously saturated the chamois covering in a warm saline solution. Moisten the subject's hands. Place an electrode in each hand, and have the subject stand with *arms fully relaxed.* Select in succession:

a. An uninterrupted direct current with alternate polarity.

b. An interrupted direct current with alternate polarity.

Set the machine so that the subject receives approximately 20 surges per minute. Connect meter to read on low scale (0 to 15 ma.). Increase the current gradually to tolerance, and record your observations in Table 12. Vary the number of surges per minute and note the effect.

Observations:

1. *Demonstration of Polarity Change:* It will be observed from the liberation of iodine that the polarity of the electrode in each hand is alternately positive and negative, and also that while the polarity of one hand is positive, the polarity of the other is negative. Fig. 41. In this experiment the electrodes are alternately positive and negative. When the left hand electrode is at a given positive electrical potential, the right hand electrode is at an equal negative potential. At points equidistant from the electrodes, the electric potential is zero. The difference in potential between the two electrodes is equal to the positive potential of the one minus the negative potential of the other. If we assume the left hand electrode is at a potential of +10 volts when its positive potential is greatest, the right hand electrode will be at a potential of —10 volts at this instant, and the difference in potential will be 10 — (—10) or 20 volts. This is the voltage read at that instant on a voltmeter connected across the electrodes. In Fig 42 is shown schematically the potential variation of the electrodes and the liberation of iodine during the positive phase.

2. *Tissue Reactions:* Data similar to that recorded in Table 12 should be secured on a number of subjects, and the table completed.

It will be observed that the surging uninterrupted direct current

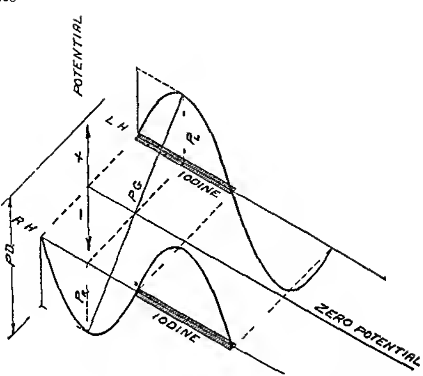

FIG 42 Schematic representation of the potential variation of the electrodes and the liberation of iodine during the positive phase for a surging uninterrupted direct current with alternate polarity P_L represents the potential of the left hand electrode and P_R that of the right hand electrode. P D is the difference in potential between the two electrodes The line P G shows the potential at points between the electrodes and is called the *potential gradient* At points midway between the electrodes (assuming the dielectric between the electrodes to be homogeneous) the potential will be zero

with alternate polarity (so called sinusoidal current) is relatively ineffective for producing contraction of normal skeletal muscle On the other hand the surging interrupted direct current with alternate polarity produces marked contractions It is obvious that this difference in muscle stimulation is not entirely due to either current intensity or voltage as read by meters, for in all instances the current reading was markedly higher, and the voltage reading much higher, when the uninterrupted current was used The average ratio of current intensities will be found to be about 3 to 1

TABLE 12

	Surging Interrupted Direct Current Alternate Polarity				Surging Uninterrupted Direct Current Alternate Polarity			
Subject No	M A	Volts	Heat Sense	Muscle Stimulation	M.A	Volts	Heat Sense	Muscle Stimulation
1	4	12	None	Marked	15	40	Marked	Slight
2								
3								
4								
5								
6								
7								
8								
9								
10								

It should also be noted that when the uninterrupted current was used, a sense of heat was eventually felt in the wrists and forearms, which occurred after the subject's resistance was at a minimum On the other hand, no such sensation could be noted when using the interrupted type of current A surging direct current, interrupted at the rate of 40 to 120 times per second, more nearly meets the chronaxie requirement of the normal skeletal muscle than does the uninterrupted type of current as already explained Hence, with such a current a maximal contraction can be secured with a minimal current intensity. Obviously, therefore, less heat should be generated by this current.

Furthermore, close observation will show that for each surge of the current the muscles of one arm will contract more vigorously than those of the other. The more vigorous contraction occurs

during the negative phase This illustrates the normal polar formula for muscle contraction, CCC > ACC The degree of difference will vary somewhat with different individuals

Conclusion

A surging interrupted direct current with alternate polarity is best suited for stimulating normal skeletal muscle

Note

Each of the various currents on the machine should be similarly tested In this manner, an approximate idea can be obtained as to how each current may, or may not, differ from the other from the viewpoint of producing contraction In this way, data can be secured to aid in selecting the best current on a particular machine for stimulating the normal skeletal muscle The current selected should be that current which produces the maximal contraction with minimal current intensity

PART B MUSCLE STIMULATION BY ELECTRIC CURRENTS

SECTION THREE TECHNIC OF APPLICATION

I DISORDERS OF THE NERVOUS SYSTEM In using electrical stimulation for the treatment of muscles involved in nerve injuries, consideration must be given to the following important points

1 The patient should never be permitted to fall into a false sense of security Treatment by stimulation should not preclude an *active* effort on the part of the patient
2 Stimulation of a muscle should be carefully prescribed and undertaken only by those properly trained in this field
3 In the treatment of lower motor nerve lesions, fatigue should be carefully avoided
4 Electrical stimulation should be used in combination with heat, massage, and re-education of the muscles
5 A muscle cannot function unless the nerve supply returns, and it is doubtful whether any of the above measures materially shortens the period of regeneration Their use is important, however, to keep the muscles in as good condition as possible until function returns
6 *Physiological rest* must be provided at all times, including the period of treatment

A. *Lesions of Lower Motor Neurons* Lower motor neurons have their origin in the anterior horn cells of the spinal cord, their terminal branches enter the skeletal muscles and terminate in the motor end plate The cell is the life center of neuron activity If, because of the effects of infection, or, if, as the result of trauma, the nerve is separated from its cells, the nerve fibers will gradually degenerate, and the degeneration will extend clear to the terminal endings (Wallerian degeneration) If the lesion is distal to the cell, then degeneration of the nerve occurs peripherally below the lesion, and for a very short distance centrally (toward the cell); in addition, other changes occur in the intracellular elements of the cell body, which for this discussion need not be considered. Nerve cells do not regenerate, and so, if the cells are destroyed, their nerve fibers will not recover, or regenerate, no matter what treatment may be instituted. On the other hand, if the effects of infection are overcome and the sequellae of trauma repaired, so that a pathway is clear for the regeneration of new fibers down the empty nerve sheath either from the cell or from the central stump, then regeneration takes place and anatomical recovery occurs even without treatment, functional recovery, however, may not occur without adequate treatment.

The object of treatment then is to maintain the best possible conditions while regeneration is in process According to histopathologists, there is no way by which we can accelerate the normal process of regeneration of nerves, which normally occurs, they state, at approximately one to two millimeters a day Nevertheless, much can be accomplished by appropriate treatment to keep the condition of the muscles such that when regeneration does occur, the muscles are ready to resume their function immediately. Before the Royal Society of Medicine, Bauwens[1] recently stated

With regard to the value of artificially produced muscle exercise in paralysis, on the assumption that function improves the organ, I believe

[1] Bauwens, P. Electro-Diagnosis and Electrotherapy in Peripheral Nerve Lesions Proc Roy Soc Med 34 459-468 (June) 1941

in electrical stimulation of paralyzed muscles, for although it does not prevent atrophy, circulation and nutrition are improved. To be effective and non-injurious it is important to use a technic which will not produce contractions in normal muscles surrounding and opposing the paralyzed ones Fatigue must be avoided by allowing long pauses of rest between contractions which should be few in number.

Flaccid paralysis is the outstanding sign common to all lower motor neuron lesions regardless of etiology. The lesions may result from radically different causes, such as: infections, for instance, infantile paralysis; the sequellae of infectious diseases with resulting polyneuritis, a physiological block as a result of continuous pressure from tumors, plaster casts, or even crutches; and traumatic injuries of a minor or major nature. The location of the pathological condition may be anywhere from the anterior horn cells, as in anterior poliomyelitis, to the terminal nerve endings in the muscles themselves. However, *regardless of these differences*, the *principles of treatment* are essentially the same for all lower motor neuron disorders If the nerve cell is present and the nerve sheath is intact, the axis cylinder will regenerate with or without treatment. The end or functional result, however, will depend on the care and treatment accorded to the paralyzed muscles involved It is necessary, therefore, to devote our entire attention to the *muscles*—while nature is attending to the nerve regeneration.

The use of electrical muscle stimulation as one of the therapeutic measures to be followed in the treatment of poliomyelitis should be given special consideration Once the acute and subacute stage has subsided and it is safe to use physical therapy treatment, then electrical muscle stimulation can be used for those muscles showing complete paralysis; but for those muscles which exhibit a condition of paresis, rather than complete paralysis, electrical muscle stimulation should be attempted only by those who are sufficiently expert to select the electric current best suited to fit into the chronaxie of the *paralyzed fibers*—otherwise it is better not to use this form of therapy.

The muscles of patients suffering with polyneuritis of the type that demonstrates a physiologic loss of function but in which the

anatomical continuity of the nerve is present, do not show the reaction of degeneration, in fact, they show a state of hyper excitability The muscles of these patients should not be stimulated by electric current until after the acute and subacute stages

1 *Object of Treatment*

a To maintain *as much as possible* the tone and nutrition of the affected muscles

b To prevent *as much as possible* atrophy of the muscles by rhythmical contraction According to Tinel, this will assist in preventing subsequent deformity

c To maintain *as much as possible* the state of muscle irritability during the period of time that nerve regeneration is taking place so that when the new nerve fibers reach the muscle it will be able to resume immediately its normal function

d Tinel states that electrical stimulation actually hastens the rate of nerve regeneration Whether the rate of nerve regeneration is accelerated by electrical stimulation of the paralyzed muscle is open to question The rate of regeneration may appear to be increased because of the early detection of functional return, resulting from the continuous observation associated with the administration of electrical muscle stimulation

2 *Technic of Treatment*

a The referring physician should provide an exact diagnosis of the nerve lesion The extent of the lesion will determine whether to treat the muscles individually or as a group

b *Patient* Should be placed in such position that the paralyzed muscles are in a state of *Physiological Rest* (see Wm Colin Mc Kenzie *Action of Muscles*)

c *Part under treatment* Must be in a good light to avoid shadows so that spurious effects due to the current flowing to contiguous muscles may be observed and evaluated

d *Treatment* Should be preceded with some form of heat for 15 to 20 minutes to help lower the electrical resistance of the skin The degree of anesthesia present determines the degree of care to be exercised in the application of heat

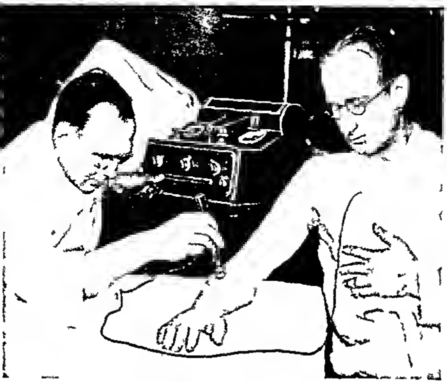

FIG 43 Illustrating the unipolar technic of muscle stimulation

e *Selection of Current* The surging uninterrupted direct current with alternate polarity should be employed for any muscle showing the reaction of degeneration, for the reasons set forth in Section One The period of relaxation is as important as the period of contraction Knowledge of the time required for the paralyzed muscle to relax completely after contraction, which is determined by observation, indicates the number of stimulations to be applied per minute in the treatment of the muscle

f *Application of Electrodes* The electrodes, made of some absorbent material are similar to those used for the application of direct current and are similarly prepared There are two methods of application

(1) *Unipolar* One electrode is active, the other dispersive The dispersive electrode, the larger of the two, is properly prepared and applied to either the anterior or posterior portion of the trunk The

smaller or active electrode, of variable shape and size, is attached to a handle made for this purpose, and applied to the motor point or at the point of election Fig 43 For motor point chart, see page 89, Fig 24

(2) *Bipolar* Both electrodes are of equal size and similar to the active electrode used with the unipolar method They are applied so as to include the extremities of the muscle belly Fig 44 This method is used where it is necessary to reduce skin resistance to an absolute minimum Furthermore, the current will not overflow into neighboring muscles quite so readily when this technic is used

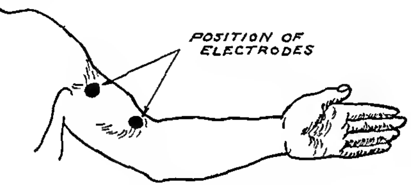

Fig 44 Illustrating bipolar technic with the electrodes at the extremities of the muscle

g *Duration of Treatment* It is important not to over stimulate Always treat short of fatigue A muscle that is paralyzed fatigues rapidly, the onset of fatigue can be detected by the change in the nature of the contraction such as a slowing or a complete disappearance of the contraction

h *Important Note* In paralysis it is imperative to allow sufficient time for lowering skin resistance With minimum skin resistance and proper application of electrodes, the voltage required for a given current will be a minimum The active electrode should not be continually moved from place to place simply because the muscle contraction is not immediately secured The technician should learn to detect minute or incipient contractions by means of the fingers placed over the tendons of the muscles

under stimulation, because sometimes while the muscle contraction cannot be seen, it can be felt at its tendinous insertion.

3. *Prescription.* The following prescription should be provided by the referring physician.

a. *Muscles To Be Stimulated.*

b *Current.* Surging uninterrupted direct current with alternate polarity, when R.D. is present.

c. *Milliamperes.* Minimum to secure an adequate degree of contraction.

d. *Voltage.* Minimum.

e. *Contractions Per Minute.* Should be few enough to permit ample time for complete relaxation between contractions.

f. *Duration of Treatment* The treatment should not be continued beyond the onset of fatigue.

g *Frequency of Treatment.* Three times weekly.

4. *Special Applications*

a. *Paralysis of the Laryngeal Muscles:* Paralysis of varying severity may occur as a sequella to diphtheria, thyroidectomy, or aneurism of the aorta, or it may be of psychogenic origin. Like other forms of paralysis, it may be organic or psychogenic, of either nuclear or peripheral origin.

A typical hysterical paralysis presents a bilateral paralysis of the adductors of the cords, aphonia, no dyspnea, and an irregular characteristic tone of voice.

Peripheral paralysis may be unilateral or bilateral, and confined to individual muscles, or diffused over all Paralysis of the pharyngeal constrictors, causing a disturbance of deglutition so that the patient must be fed by means of a tube, is most frequently either a sequella of diphtheria or a symptom of bulbar paralysis.

(1) *Technic of Treatment* A ¾ or 1 inch absorbent electrode is connected to an appropriate handle The electrode is thoroughly saturated in a 1 per cent solution of sodium chloride. The solution should be at a temperature comfortable to the patient. This active electrode is connected to one terminal of the muscle stimulating generator, and then applied to the lateral aspect of the larynx at its mid point, and medial to the sternocleido-mastoid muscle.

Fig 45 The point of election may not always be just at the point selected, but with care and some patience can be found by slowly changing the position of the electrode on the neck It may some times be found as low as the level of the crico thyroid cartilage

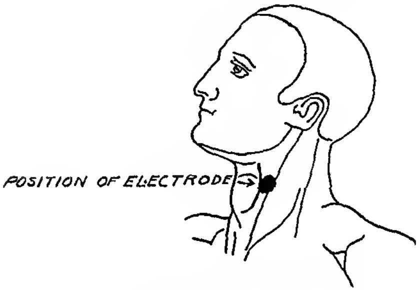

Fig 45 The point of application for the active electrode in paralysis of laryngeal muscles

The dispersive electrode is properly prepared, with the patient in a sitting position it is applied to either the chest or back and bound firmly in position by means of a rubber gum bandage This electrode is connected to the remaining terminal of the generator The physician, using a laryngeal mirror, observes the effect of the stimulation during the initial treatment while the technician applies the current

It is imperative that the current employed be the Surging Uninterrupted Direct Current with Alternate Polarity

b *Paralysis of the Facial Nerve* Paralysis of the facial nerve in which the anatomical continuity of the nerve has been interrupted is treated as any other lower motor neuron lesion However, paralysis of the facial nerve is frequently encountered in

which the anatomical continuity of the nerve is intact but its conduction is impaired because of an inflammatory process. The section of the nerve trunk most frequently affected is that portion situated between the stylo-mastoid foramen and the division of the nerve into the pes anserinus; the process may also extend farther into the fallopian canal but rarely to the geniculate ganglion

Fig 46 Illustrating a method of securing physiological rest for the facial muscles To be used continuously except during treatment

The true character of the affection is still somewhat obscure; however, there is slight doubt that it is of an inflammatory nature caused either by exposure to cold, or by infection The exposed situation of the nerve is favorable for inflammation from some unusual exposure On the other hand, the narrow calibre of the fallopian canal causes marked compression of the nerve when it has undergone slight inflammatory swelling within the canal Some patients recover within a few weeks while others may not recover for many months When facial nerve paralysis accompanies an otitis media, it may require a period of six months before spontaneous regeneration occurs

(1) *Technic of Treatment*

(a) The paralyzed facial muscles must be protected from overstretching and sagging The simplest type of support consists of the application of adhesive tape as illustrated in Fig. 46. An

Fig 47 Application of active electrode to facial nerve

upward pull must be maintained The support must be worn constantly

(b) The patient should be placed comfortably in the supine position The face of the patient should be in a good light free of shadows so that the technician may be able to avoid stimulating contiguous muscles

(c) An active electrode, consisting of an absorbent half inch disk, is attached to an appropriate handle and connected to the selected source of current This active electrode thoroughly saturated with a conductive solution, is applied either to the individual muscles or to the facial nerve directly Fig 47 Usually it is best to stimulate each muscle individually

The dispersive electrode, 4 by 6 inches in size and prepared as previously outlined, is applied under the scapula, or to any con

venient part of the body, and connected to the source of current.

(d) Selection of current will depend on whether R.D. is present or not. If R.D. is complete, then the surging uninterrupted direct current with alternate polarity is selected; but if R.D. is not present, then the surging interrupted direct current with alternate polarity is used. The rate at which the muscle should be contracted will depend on the degree of sluggishness exhibited by the muscle. The muscle must be permitted to relax completely between contractions. Stimulation of the muscle should not be continued to the point of fatigue of the muscle; stimulation should be discontinued before this point is reached.

B. *Lesions of Upper Motor Neurons:* The great motor path from the cerebral cortex to the skeletal musculature, through which the bodily activities are placed directly under voluntary control, is in man and mammals the dominant factor in the motor mechanism. Afferent paths from the various exteroceptors reach the cerebral cortex; and through the correlation of the olfactory, auditory, visual, tactile, thermal, and painful afferent impulses which pour into it, there is built up within the cortex a representation of the outer world and its constantly changing conditions The responses appropriate to meet the entire situation in which the individual finds himself from moment to moment are, in large part, initiated in the cerebral cortex and are executed through the motor mechanism.

This great motor path consists of an upper and a lower motor neuron unit. The so-called upper motor neurons conduct impulses from the motor cortex They originate in the giant pyramidal cells of the motor cortex, and terminate in the motor nuclei of the cerebral nerves, or in the anterior gray columns of the spinal cord, whence the lower motor neurons relay the impulses to the muscles

Because of a decussation of these fibers in the caudal part of the *medulla oblongata*, *muscular contractions produced by cortical* stimulation occur chiefly on the opposite side of the body. Therefore, lesions in the pyramidal system above the decussation are contralateral.

While injury to a lower motor neuron is associated with atrophy and a flaccid paralysis, injury to an upper motor neuron leads

to a loss of function without atrophy but with an increased tonicity of the affected muscles producing spastic paralysis A restricted cortical lesion may cause a monoplegia or a paralysis of a single part, such as an arm or a leg If the internal capsule is involved the resultant paralysis is apt to be a hemiplegia, because all the motor fibers (pyramidal tract) are grouped within a small area The paralysis will be of the opposite half of the body

The function of the pyramidal tract is to initiate voluntary movements and make skilled (praxic) movements possible, to exert an inhibitory effect over the anterior horn cells concerned in spinal reflexes, to exert a tonic inhibitory effect over the anterior horn cells concerned with the extensor or postural (anti gravity) muscles and to exert a reinforcing influence on flexor movements

Spastic paralysis presents an exaggeration of postural reflexes The arm is held in a typical manner with the shoulder adducted, the elbow semi flexed and the wrist and fingers partially flexed There is adduction of the leg with extension of the knee and foot —producing a circumduction gait The muscles do not show the reaction of degeneration but hyperirritability

1 *Object of Treatment*

The object of treatment is to stimulate the least spastic group of muscles in an effort to counteract the ill effects of constant overstretching The object of all forms of treatment for the spastic is to assist the patient in acquiring co ordination of movements This objective may be achieved through the use of various rhyth mical procedures When using electrical muscle stimulation, the muscles must be stimulated in a rhythmical manner, so that the patient may gain an appreciatioo nf rhythmical muscular re sponse

2 *Technic of Treatment*

a *The Patient* Should be in the recumbent position The sur roundings should be conducive to complete relaxation Some form of heat, followed by gentle centripetal stroking massage to pro duce complete relaxation should precede the electrical treatment The muscles may be stimulated tn fatigue, nr until the signs of

spasticity return, as manifested by clonic movements of the agonists.

b. *Electrodes.* The unipolar method of application is employed. The electrodes are prepared as described for direct current. The active electrode, a 1-inch to 1½-inch disk, is applied directly to one or more of the nerve trunks supplying the extensor muscles, depending upon the extent of the lesion Consult motor point chart, Fig 24, page 89, to locate the following nerve trunks: radial; femoral; aod common peroneal (external popliteal)

c. *Prescription*

(1) *Muscles* to be stimulated.
(2) *Current* Surging interrupted direct current with alternate polarity.
(3) *Milliamperes.* Adequate to secure full muscle contraction.
(4) *Voltage.* Minimum
(5) *Contractions Per Minute.* 15 to 20.
(6) *Duration of Treatment.* Until spasticity or onset of fatigue is reached
(7) *Frequency of Treatment.* 3 times weekly.

d *Discussion.* It must be kept in mind that only the less spastic muscles are treated The spastic muscles usually are the flexors and internal rotators of the upper extremity, and the extensors, internal rotators, and adductors of the lower extremity. Hence, treatment is directed to their agonists The simplest method, therefore, is to stimulate these muscles through the nerve supplying them One can, however, stimulate individual muscles, or groups of muscles, if it is considered to be more advantageous

II. Strains, Sprains, and Dislocations

A. *Object of Treatment*

To assist in the removal and resolution of the vascular and lymphatic exudates which form as the result of trauma to the small arterioles and lymph channels An appropriate type of current, applied to the muscles controlling the joint, should assist in removing the exudates about the joint by giving a mechanical

massage without producing further trauma to the tissues This massage is physiologic in type, not possible to produce by hand This form of therapy is excellent for the treatment of these pathologies, especially if administered early It very closely simulates nature's own method of massage Depending upon the severity of the lesion that a joint sustains, any or all of its various structures may be damaged to a greater or lesser degree; but in every case, the muscles activating the joint always suffer In joint injuries, or even in joint diseases, there is a wasting of the muscles that control the joint, and the wasting is not only *passive from disuse,* but *active from nutritional reflex,* because of the fact that the joint and the muscles moving the joint are supplied by the same nerve According to King and Holmes[4] this atrophy can take place in forty-eight hours when the joint injury is severe. Since joint function is dependent on muscular tone, electrical stimulation of the muscles should be used early, thereby combatting atrophy due to active nutritional reflex In knee joint injuries, the vastus internus head of the quadriceps muscle is most likely to suffer.

B *Technic of Treatment*

1. *Preliminary Preparation* Use some form of heat—preferably inductothermy.

2 *Electrode Application* The unipolar method is usually most satisfactorily employed The active and dispersive electrodes are prepared as previously described The active electrode may be:

a A small circular 1-inch absorbent disk; applied: (1) Directly to the nerve trunk which supplies the muscles in need of stimulation (2) Directly to each individual muscle or to some one particular muscle of a group which may need special attention, such as the vastus internus muscle of the knee joint The electrode is applied at the motor point of the muscle to be stimulated

b. A large electrode, approximately 4 by 6 inches, which is used for stimulating simultaneously large groups of muscles such as the hamstrings or quadriceps femoris. The electrode is held in place by the hand of the technician over the muscles to be stimulated

[4] King, J M, Jr, Holmes, G W Diagnosis and Treatment of 450 Painful Shoulders J A M A 89 1956 1961 (December 3) 1927

stress is placed upon the ligaments supporting the bony parts of the arch, causing pain. Because the plantar nerves become irritated, the first step should be to provide a properly designed and flexible support for the arch; following this, electrical muscle stimulation and special foot exercises are instituted.

B. *Technic of Treatment*

Secure two oblong metal pans, Fig 48. Place in each a small amount of warm water to which sodium chloride (NaCl) or sodium bicarbonate ($NaHCO_3$) has been added Place a piece of orthopedic felt in the bottom of each pan, large enough for contact with the entire plantar surface of the foot. The water should just cover the feet

Connect the two pans to one patient terminal of the generator by means of a bifurcated connecting cord. These pans serve as the dispersive electrode The two active electrodes, 1 to 1½ inch disks of absorbent material, are connected to the other patient's terminal by means of a bifurcated cord

The disk electrodes are applied either to the common peroneal nerve or to its individual muscles The common peroneal nerve is usually located just below, or in the region of, the neck of the fibula. Sometimes the current will stimulate the peroneus longus and peroneus brevis rather than the more important tibialis anterior. If this occurs, the active disk electrode should be moved gradually toward the motor point of the tibialis anterior without removing the electrode from the skin The muscle movement to be secured should be that of inversion, alternated with flexion of the toes Once the correct position for the electrodes is found, they can be bound in place by special straps made for this purpose, or held in place by the patient by means of a wood handle fastened to the disk electrodes.

C. *Prescription*

1. *Muscles* Those that will produce inversion of the foot and plantar flexion of the toes
2. *Current.* Surging interrupted direct current with alternate polarity.

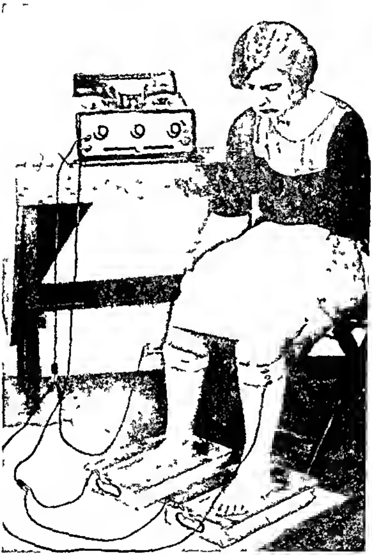

FIG. 48 Technic of application for pronated feet due to muscular weakness Note method of securing disk electrodes in position

3 *Milliamperes* 5 to 15
4 *Voltage* Minimum
5 *Duration of Treatment* Until onset of fatigue
6 *Contractions Per minute* 10 to 20
7 *Frequency of Treatment* Daily.

V Muscular Atrophy of Disuse

A *Object of Treatment*

The forced inactivity of patients who are confined to bed for prolonged periods, causes nutritional disturbances, resulting in marked atrophy and atony of all muscles, but especially of those of the extremities and the abdomen Such atrophy, it is claimed, may be controlled by electrical muscle stimulation used adjuvantly

B *Technic of Treatment*

The unipolar or bipolar method can be used The bipolar method has the advantage of stimulating a greater number of muscles simultaneously

1 *Unipolar Electrode Application* The active electrode should be of an appropriate size and shape, ranging from a 1½ inch disk to a 4 by 6 inch pad The electrode selected is thoroughly saturated in a warm saline solution and applied over the muscles to be stimulated A dispersive pad electrode is similarly prepared and applied to either the posterior or anterior region of the trunk and maintained in firm contact with the skin

2 *Bipolar Electrode Application* Two pad electrodes of the same size are used The size of these electrodes will depend upon the group of muscles to be stimulated, 4 by 6 inch electrodes are usually employed Muscles of the trunk or abdomen are stimulated by applying the electrodes to corresponding muscles on each side of the spine or abdomen A muscle of an extremity is stimulated by applying the electrodes so as to include the belly of the muscles Fig 44, page 146

C *Prescription*

1 *Muscles* Those requiring stimulation
2 *Current* Surging interrupted direct current with alternate polarity
3 *Milliamperes* 5 to 15
4 *Voltage* Minimum

5 *Duration of Treatment* Until onset of fatigue
6 *Contractions Per Minute* 10 to 20
7 *Frequency of Treatment* Daily

VI Constipation (Atonic Form)

A *Object of Treatment*

It has been claimed that colon motility can be initiated by the use of electric current Two methods of application are employed One method stimulates the extrinsic muscles of the abdominal wall, such stimulation, it is claimed, initiating colon motility, while the other method is supposed to stimulate the colon through the autonomic nervous system These claims have never been definitely established However, the treatment seems to have as rational a basis as the use of mechanical massage

Management of this condition requires individualization and is not simple In addition to electrical stimulation, attention must be given to diet, water intake, abdominal support, exercise, the changing of the intestinal flora, and physical and mental rest

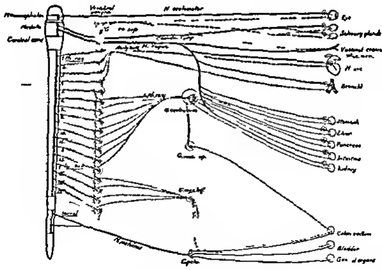

Fig. 49 The autonomic nervous system modified from Meyer and Gottlieb (From Ransom The Anatomy of the Nervous System, 5th Edition W B Saunders Company Philadelphia 1936)

B *Technic of Treatment*

1 *Stimulation of the Autonomic Nervous System* It has been suggested that the best method of dealing with constipation is stimulation of the colon by applying the current in the region of those sympathetic ganglia whose post ganglionic fibers originate in the celiac and inferior mesenteric plexuses However, it has neither been proved nor disproved that colon motility can be influenced by such stimulation Fig 49

a *Technic* Prepare the treatment table with a full sized rubber sheet over the mattress With the patient stripped to the waist and in the standing position, mark the location of the inferior angle of the scapula With the patient on the table in the sitting position, apply two 4 by 6 inch electrodes so that their upper borders form a shelf for the inferior angle of the scapula Allow 1½ inch between the medial edges of the electrodes, which are also equidistant from the spinous processes Place a rubber sponge—the larger the

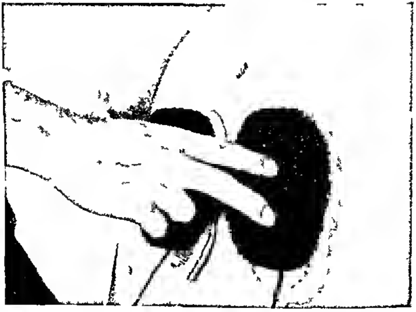

FIG 50 Position of electrodes on either side of spine and beneath the inferior angle of the scapula

FIG 51 Patient reclining preparatory to assuming final prone position for treatment.

sponge, the better—over the electrodes and have the patient lie down in position without disturbing the conducting cord contacts, electrodes, or sponges Figs 50 and 51 Connect the two cord terminals to the generator The current is very gradually increased to the required level

b *Prescription for Stimulation Through Autonomic Nervous System*

(1) *Current* Surging uninterrupted direct current with alternate polarity

(2) *Milliamperes.* 30 to 60, or such intensity as to produce movement in the region of the umbilicus.

(3) *Voltage.* Minimum.

(4) *Duration of Treatment.* 10 to 20 minutes.

(5) *Contractions Per Minute.* 12 to 15.

(6) *Frequency of Treatment.* Daily.

c *Discussion.* The patient, during the early part of the treatment, feels a prickling sensation equally beneath both electrodes This is caused by the continuously decreasing electrical resistance of the skin, and it persists until the resistance has reached a constant level. It is followed by a sensation of heat at both electrodes, which may be intense enough to make the patient believe he is being burned. The operator must be sure that no burn is occurring, and if the application is correctly made, and the current intensity not excessive, no burns will occur. This phase is followed by the patient sensing greater irritation, first under one electrode and then under the other, alternating with change in polarity of electrodes—being greater when the polarity is negative. The greater irritating effect of the negative electrode was experimentally determined in Experiment 7, page 24 But, as the current is gradually increased, the patient should begin to feel contraction in the abdomen; this occurs usually when the current intensity reaches approximately 20 to 30 ma. The operator will not be able to observe it, but must rely on the subjective sensation of the patient As the current is gradually increased, the operator will eventually observe slight movement of the umbilicus, but contraction of the extrinsic abdominal muscles is rarely observed Occasionally, however, this technic does not produce the typical movement of the umbilicus, but instead produces marked contraction of the extrinsic abdominal muscles.

For this application it is important to use the surging uninterrupted direct current with alternate polarity.

2. *Stimulation of the Extrinsic Muscles of the Abdominal Wall*

a. *Technic.* (1) The patient is placed in the supine position, and two 4 by 6 inch electrodes are applied to the abdominal muscles, equidistant from the mid line of the abdomen A rubber sponge is placed over each electrode, and held in place by applying a

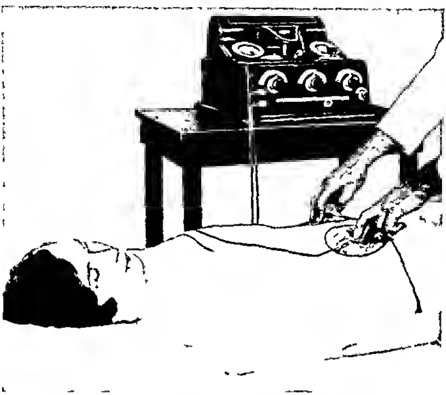

FIG 52 Application of both electrodes to the abdomen for the stimulation of the extrinsic muscles of the abdominal wall

canvas band reaching over each side of the treatment table with sandbags suspended from the hooks provided for that purpose. Fig. 52.

(2) A large dispersive pad, 6 by 8 inches, is applied under the sacrum, and the active electrode, 4 by 6 inches, is applied over either the ascending, transverse, or descending colon. It is held in place as described above, or moved from segment to segment of the abdomen while held in place by the operator. Fig. 53. In view of the fact that it is difficult, if not impossible, to determine the exact position of any one segment of the colon, it is our opinion that the technic of application outlined under (1) is to be preferred. Furthermore, this technic is to be preferred because it provides a gentle, rhythmical massage of the entire abdominal viscera.

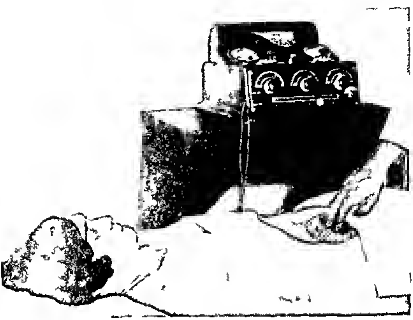

Fig 53 Application of the active electrode to the abdomen and the dispersive electrode under the sacrum The active electrode is applied successively to the regions of the abdomen where the ascending transverse and descending segments of the colon are popularly thought to be located The exact position of the various segments of the colon is a debatable question

b *Prescription for Stimulation of Abdominal Muscles*

(1) *Current* Surging interrupted direct current with alternate polarity

(2) *Milliamperes* 10 to 15

(3) *Voltage* Minimum

(4) *Duration of Treatment* 10 to 30 minutes, or to point of fatigue

(5) *Contractions Per Minute* 12 to 15

(6) *Frequency of Treatment* Daily

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VII. Graduated Electrical Muscle Contraction (Surging Tetanic or Faradic Contractions). It is unfortunate that the term "Graduated Muscular Contraction" is used by many workers in place of the more descriptive term *Graduated Electrical Muscle Contraction*, because it may be confused with active exercise therapy. The proponents of this technic use either a manually operated *Bristow Coil* or the *Morton-Smart* type of apparatus. The same results can be secured with any type of apparatus employing a surging tetanizing current. It is difficult to see any specific advantage in employing a manually surged tetanizing current over an automatically surged tetanizing current. The use of the automatically surged interrupted direct current with alternate polarity for the production of graduated muscular contractions has been fully explained.

A. *Technic of Graduated Electrical Muscular Contraction as Applied to the Quadriceps.* The *Faradic Coil* or the *Bristow Coil* is set with the selector switch turned to S (secondary). With the switch in this position, the current induced in the secondary coil is applied to the patient. The current intensity is switched to Button 1, 2, or 3, according to the required current intensity. Button 1 gives the lowest current strength, and is the one usually selected at the beginning of the treatment. The core of the coil is set in such position—in some apparatus all the way in, and in others all the way out—that the intensity of the secondary current is insufficient to produce a contraction.

The patient lies on the treatment table in a comfortable position, completely relaxed. A support is placed under the knee joint to relieve tension on the posterior ligaments of the knee. A large dispersive electrode of suitable dimensions, approximately 6 by 8 inches, is placed under the buttocks or beneath the thigh. Good contact must be assured between this electrode and the skin of the patient. The active electrode, usually a 4 by 6-inch pad, or as some technicians prefer, a 2 to 3-inch absorbent disk type electrode, is applied directly over the quadriceps muscle and held by the op-

erator's hand directly so that the muscular contraction can be felt The apparatus is so placed that the technician can readily manipulate the core, thereby surging the tetanizing current obtained from the secondary winding Fig 54

The current switch is turned on, and the vibrator interrupting the primary current is set in motion The rate of vibration should be very rapid The core is now manipulated by the technician so

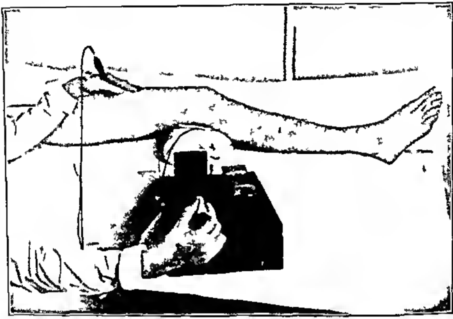

Fig 54 Technic of graduated electrical muscular contractions as applied to the quadriceps (From Reimann H A. Treatment in General Medicine. F A. Davis Co Philadelphia 1939)

that the current strength is gradually increased to secure the desired degree of contraction The hand of the technician appraises the degree of muscle contraction When the desired degree of contraction is secured, the core of the coil is gradually returned to its former position Fig 54 Thus a rhythmical cycle of contraction is secured The degree of contraction to be produced will depend on the condition of the muscles The muscle should always be permitted to relax completely between successive contractions

VIII HYSTERICAL PARALYSIS Hysterical or functional paralysis frequently occurs as the result of some injury There is no anatomical break or physiological block of the nerve involved The neuromuscular pathway is intact, but the muscles fail to function simply because the patient believes he cannot, and hence does not, initiate the necessary nerve impulses to actuate the muscles

The treatment of such a condition becomes a psychological problem The patient must be convinced that voluntary movement of the muscles involved is possible He may be convinced by demonstrating to him that the muscles respond like any other unaffected muscle to the tetanizing current It should be explained to him that if the affected muscles were paralyzed, they could not respond to this type of current It may be necessary to produce painful tetanic contractions to convince the patient that his muscles are normal

A *Technic of Treatment* A source of tetanizing current is employed The unipolar technic is used One large dispersive electrode, prepared in the usual manner, is applied to any convenient part of the body The active electrode, usually a 1 inch disk of the absorbent type, is prepared, attached to a make and break key, and connected to one terminal of the generator The electrode is applied to the motor point of the muscle to be treated The make-and break key is closed, and the current intensity increased to the point where an adequate tetanic contraction is secured The contraction should be maintained to the point of severe pain in order that the patient may be impressed with the fact that the muscle does respond normally

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PART C RADIATION

SECTION ONE GENERAL CONSIDERATIONS

I Definition Radiation, or radiant energy, is energy in that form which can be transmitted through space without the support of a material medium, such as a gas, a liquid, or a solid According to Clerk Maxwell, radiation is the result of vibrating electric charges These set up alternating magnetic and electric fields at right angles to each other and to the direction of propagation, which pass on the energy from one portion of the hypothetical ether to the next as an electromagnetic wave This concept of radiation has been very successful in explaining many of the electrical and magnetic properties of radiation, and will serve so far as this discussion is concerned Radiation will, therefore, be considered as the propagation of an electromagnetic wave, and the energy of radiation as electromagnetic energy

II Velocity of Propagation Radiation is propagated through space at the tremendous velocity of approximately 186,000 miles per second, corresponding to about 300,000,000 meters per second

Its velocity varies, however, with the medium, being less in substances like glass, water, and carbon disulphide than it is in air Air, too, exerts a retarding effect on the velocity of radiation entering it from space, but for all practical purposes we may consider the velocity of radiation in air the same as that in space, namely, *300,000,000 meters per second*

III WAVELENGTH Since radiation is a wave disturbance, it must have a wavelength The length of one wave is the linear distance, in the direction of propagation, between two points of the disturbance which are in the same phase, that is, the distance for example, between successive crests or troughs, so to speak of the disturbance The unit of linear measurement to be employed will depend upon the type of radiation being considered In Table 13 are given the units in common use and their equivalents in the metric system

TABLE 13

UNITS OF WAVELENGTH

Unit	*Abbreviation*	*Metric Equivalent*
Meter	m	
Centimeter	cm	centimeter
Millimeter	mm	millimeter
Micron	μ	001 millimeter
Millimicron	$m\mu$	000001 millimeter
Angstrom Unit	Å or A.U	0000001 millimeter

A conception of the magnitude of an angstrom unit can be obtained by imagining a millimeter elongated until it extends 10,000 000 millimeters, or 10,000 meters, or 6 2 miles An angstrom unit would then be represented by one millimeter on this scale

IV FUNDAMENTAL WAVE RELATION The number of complete vibrations or wavelengths of radiation passing a given point in space per second will be equal to the velocity at which the wave disturbance is propagated divided by the wave length of the radiation If V is the velocity, λ (lambda) the wavelength and n the

frequency of vibration, or the number of complete waves passing a point every second, the relationship can be expressed by the following simple equation:

$$n\lambda = V^*$$

V. VISIBLE RADIATION. The fact that ordinary white light, i e, radiation capable of exciting the sensation of vision, is complex in structure and is composed of various wavelengths of radiation, was not suspected until Newton, by means of a prism, dispersed a beam of sunlight into a series of colors ranging from red through orange, yellow, green, and blue to violet, Fig 55 To this series of colors, Newton applied the term *spectrum* There are, in fact, many more colors in the visible spectrum than those enumerated by Newton Red changes by imperceptible degrees into orange, and orange into yellow, and so on to the violet It is impossible

* In using this equation care must be taken that λ and V are both expressed in the same unit For example, if the velocity is 300,000,000 meters per second and the wavelength is 5000 angstrom units, the vibration frequency is found as follows

$$V = 300{,}000{,}000 \text{ meters per second}$$

$$\lambda = 5000 \text{ A.U} = 5000 - 10{,}000{,}000 \text{ mm.} = \frac{5}{10{,}000} \text{ mm}$$

$$= \frac{5}{10{,}000} - 1000 \text{ meters} = \frac{5}{10\,000{,}000} \text{ meters}$$

$$\text{and } n = \frac{V}{\lambda} = 300{,}000{,}000 - \frac{5}{10{,}000{,}000}$$

$$= \frac{300{,}000{,}000 \times 10{,}000{,}000}{5}$$

$$= 600{,}000{,}000{,}000{,}000 \text{ or}$$

600 trillion vibrations per second

To find the wavelength, knowing the frequency of the vibration, divide the velocity by the frequency, obtaining the wavelength in terms of the unit used in expressing the velocity For example, if the vibration frequency of the radiation is 10 megacycles or 10,000,000 cycles, the wavelength would be 300,000,000 meters per second divided by 10,000,000 cycles per second, or 30 meters Expressed in the form of an equation,

$$\lambda = \frac{V}{n} = \frac{300{,}000{,}000}{10{,}000{,}000} = 30 \text{ meters.}$$

to detect by the human eye, definitely, where one color ends and the next in the spectral series begins. There is, in fact, an infinity of different hues and shades in the visible spectrum into which white light may be dispersed by a prism The fact that white light is composed of a series of colors was further demonstrated by Newton by re-combining by means of prisms the various colors into which white light was dispersed, thereby again obtaining white light.

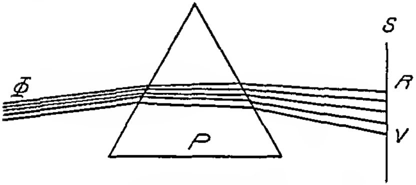

FIG 55 Dispersion of white light into its component colors by means of a prism

VI. INVISIBLE RADIATION. Herschel, in 1800, discovered the existence of invisible radiation in sunlight By placing the blackened bulb of a thermometer beyond the red of the visible radiations of the spectrum into which a beam of sunlight was dispersed, the presence of radiant energy was detected, which on absorption by the blackened bulb was transformed into heat, causing a rise in the reading of the thermometer. To such heat producing radiation lying below the red in vibration frequency the term *infrared* is applied. The complete range of infrared radiation extends from the limit of the visible spectrum, through the invisible radiation emitted by hot bodies, to the relatively low frequency or long wavelength radiation employed in radio communication

The next year, Ritter discovered the presence of radiation beyond the violet of the visible spectrum by placing there a piece of

paper moistened with a solution of a silver salt The effect of the radiation on the silver salt was to liberate silver, and cause a blackening of the paper. The effect of these radiations beyond the

TABLE 14
ELECTROMAGNETIC SPECTRUM

Radiation		Wavelength Limits in A U
Cosmic rays		Less than 0001
Gamma rays		01 - 1 4
Roentgen rays		01 - 120
Ultraviolet	Far	120 - 2900
	Near	2900 - 4000
Visible	Violet	4000 - 4500
	Blue	4500 - 5000
	Green	5000 - 5500
	Yellow	5500 - 6000
	Orange	6000 - 6500
	Red	6500 - 8000
Infrared	Near	8000 - 15000
	Far	15000 - 150,000
Hertzian		1,000,000 - 3×10^{14}
Radio waves used for communication		1×10^{11} - 3×10^{14} or 10 meters - 30,000 meters

violet, to which the term *ultraviolet* is applied, is primarily chemical, whereas the effect of those in the infrared zone is thermal The entire ultraviolet portion of the spectrum extends from the limit of the violet of the visible zone through the ultraviolet

radiations, used in the treatment of calcium deficiency and other diseases, through the x rays and the gamma radiations of radium to the cosmic rays All of these radiations travel with the same speed, and differ only in their vibration frequency and, consequently, in their wavelength The entire known electromagnetic spectrum with the approximate limits in wavelength and vibration frequency of the various zones into which, for the sake of con venience, the spectrum is considered divided, is shown in Table 14

The entire known electromagnetic spectrum extends from 30,000 meters to less than 01 angstrom unit in wavelength—a range covering 60 octaves, only one of which, namely, from 4,000 to 8,000 angstrom units, excites the sensation of vision If a scale 1 foot long were to represent the visible spectrum, a linear scale approximately 15 million miles long would be required to represent the 60 octaves of known radiation Life on this planet evolved and developed in this complex radiation environment Modification of it has marked biologic effects both on plants and animals Radia tion properly used provides a potent therapeutic and disease preventing agent The radiations with which this discussion is primarily concerned are the infrared and the ultraviolet rays, lying respectively in the spectral ranges, 8,000 to 150,000 ang strom units, and 2,000 to 3,200 angstrom uoits

A *Infrared Radiation* Every material body whose temperature is above absolute zero, that is, above the temperature at which theoretically all molecular activity ceases, emits energy in the form of radiation The rate of emission depends upon the absolute temperature of the body, increasing rapidly with increase in temperature, being in fact, directly proportional to the 4th power of the absolute temperature By doubling the temperature the rate of emission will be increased sixteeo fold

While a body radiates, it is also receiving radiant energy from other bodies So long as its temperature remains greater thao that of the other bodies, it will continue to radiate energy at a greater rate than it receives energy from those bodies Eventually, however, its temperature will approach that of the other bodies, and the rate of emission will equal the rate of absorption The earth radiates energy into space to other bodies, but so loog as the sun re

mains at a higher temperature than the earth, we can be assured of receiving more energy than we dissipate by radiation, and hence the earth's temperature will be maintained at a level necessary to life. The effect of the infrared rays which lie in the spectral zone we are concerned with, extending from 8,000 to 150,000 A.U., is the production of heat, and hence such radiation is frequently spoken of as *radiant heat*.

The spectral range of infrared radiation from 8,000 to 150,000 angstrom units is considered divided into two zones: near infrared, extending from 8,000 to 15,000 angstrom units; and far infrared, from 15,000 to 150,000 angstrom units. This classification is suggested by the penetrability of these radiations into water and tissue. This will be discussed in greater detail in subsequent paragraphs.

B. *Ultraviolet Radiation.* The ultraviolet radiation that we are concerned with in this discussion extends from approximately 3,200 to 2,000 angstroms. Radiation in this spectral band has been found to have definite biologic effects, and has been demonstrated to be useful in the promotion of normal growth, in the prevention of disease, and in the treatment of certain diseases. The effect of these radiations is primarily chemical, and hence are frequently referred to as actinic rays.

VII. Characteristic Properties of Radiation. All radiation, regardless of wavelength, has certain characteristic physical properties. In fact, the establishment of radiated energy as radiation depends upon whether the radiated energy possesses these characteristic properties. Electromagnetic radiation possesses the property of being reflected, refracted, diffracted, and polarized.

A. *Reflection* When radiation reaches a surface where there is a change of medium, such as the surface separating air and the water in a pond, some of the radiation is reflected, or turned back into the first medium, while some penetrates into the second medium.

If we consider the visible radiation emitted, let us say, by an electric lamp, impinging upon a polished plane surface such as a mirror, the reflected radiation appears to come from a lamp

beyond the reflecting surface, and not from the surface itself This is known as *regular reflection*

If the reflecting surface is rough we no longer see reflected objects The impinging radiation is reflected in all directions from

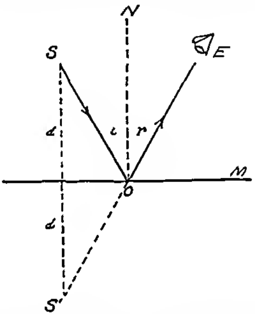

Fig 56 *Law of Regular Reflection* S is a source of radiation SO a ray striking the reflecting surface at O OE the reflected ray striking the eye of the observer *i* the angle of incidence *r* the angle of reflection The angle *i* equals the angle *r* Radiation striking the eye appears to come from a source S the image of S which is as far behind the mirror as S the object is in front of the mirror

the surface as if the surface itself were a source of light Such reflection is known as *diffuse reflection*

The law of regular reflection for radiation is the same as for other forms of wave motion If SO in Fig 56 is the incident ray, and OE the reflected one, the angles *i* and *r* which they make with the normal or perpendicular ON are the angle of incidence and the angle of reflection respectively For regular reflection the angles of incidence and reflection are equal, and lie in the same plane

The ratio of the total reflected to the total incident radiation varies with different materials for various types of radiation. Practically all of the metals are good reflectors of infrared radiation; likewise, such alloys as Duralumin, Magnalumin, Stellite Constantan, speculum metal, monel metal, and german silver. Pigments, by comparison are poor reflectors of infrared radiation. According to Koller,[1] the best of these is the compound PbO, which reflects only 26 per cent of the incident radiation at the wavelength 8.8 microns, or 88,000 angstrom units. Metals such as copper, aluminum, and chromium reflect more than 90 per cent of the normal incident radiation at the wavelength 100,000 angstrom units, or 10 microns. Water and ice are poor reflectors of infrared, being less than 2 per cent in the near infrared zone (8,000 to 15,000 angstrom units, or 0.8 to 1.5 microns), and not exceeding 5 per cent throughout the range 15,000 to 120,000 angstrom units, or 1.5 to 12 microns, the spectral range usually referred to as the far infrared zone by those who employ radiation for therapeutic purposes. Reflectors of infrared generators are usually made of copper, of aluminum, or of appropriate base metal plated with a metal having a high reflecting power, thereby increasing the intensity of the directed beam while at the same time preventing excessive temperature rise of the reflector by minimizing the absorption of radiation by it.

Aluminum and chromium are the best reflectors of ultraviolet radiation, and the specially treated *alzak* aluminum is very much superior to ordinary polished aluminum. It reflects about 85 per cent of the incident radiation in the biologically important spectral range. Silver, which reflects visible and infrared radiation well, is a relatively poor reflector for ultraviolet. Reflectors for ultraviolet are usually of treated aluminum or of chromium-plated metal to assure the maximum output of ultraviolet in the directed beam. Water, white sand, and snow have a high reflecting power for ultraviolet, as the severe sunburns obtained on the water and on the beach, and the conjunctivitis and sun blindness, contracted in

[1] Koller, Lewis R.: Infrared, Production and Transmission, Reflection and Measurement. *General Electric Review* 44 3.167 (March) 1941.

the arctic regions, attest The reflectivity of snow may be as high as 75 per cent, with a slightly frozen surface reflection may be as high as 90 per cent A patient therefore, is exposed to almost as much reflected radiation from the snow as he is to direct radiation from the sun

B *Refraction* When a beam of light passes obliquely from one

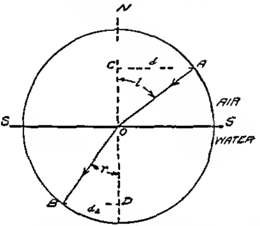

FIG 57 *Law of Refraction* S S represents the surface between two media air and water in this case N N the normal or perpendicular to this surface at the point O If a ray of light is considered to pass from air to water entering the water at O the angle *i* is the angle of incidence and the angle *r* the angle of refraction If we draw a circle of unit radius with center at *O* the half cords AC and BD of length respectively d and d_2 will represent to scale the sine of the angle *i* and the sine of the angle *r* respectively The relative index of refraction of the two media for the radiation under consideration is then the ratio of d to d_2 The relative index of refraction (air to water in this case) equals the sine of the angle *i* divided by the sine of the angle *r* or $d_1/1 - d_2/1 = 1\ 33$ The relative index of refraction water to air would be the ratio of d_2 to d_1 or 0 75

medium to another, it is usually bent at the surface separating the two media This is known as ***refraction*** The bending of a beam of light can be readily demonstrated by placing an object, let us say a coin, in the bottom of a deep dish so that it is out of sight of the observer's eye so long as the dish is empty, but on filling it with water light coming from the object is bent and comes to

the eye as if the coin had been lifted into view. Another simple demonstration is to thrust a pencil obliquely into a pan of water and observe the apparently sharp bending of the pencil at the surface.

As the beam of light passes obliquely from one medium to another of greater density, it is refracted towards the normal, or perpendicular, to the surface at the point of incidence. If the second medium is of lower density, the beam of light is refracted away from the normal. In the first case, the angle of incidence is greater than the angle of refraction; whereas in the second case, the angle of incidence is less than the angle of refraction. The exact law of refraction was discovered by the Dutch physicist Snell, some two hundred years ago, and may be stated as follows:

When light passes from one isotropic medium into another, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for light of any given wavelength, whatever may be the inclination of the incident beam; and the incident, reflected (some of the light will be reflected from the surface), and refracted rays are all in the same plane, called the plane of incidence, which is normal to the surface Fig. 57.

This constant ratio of the sine of the angle of incidence to the sine of the angle of refraction is called the *relative index of refraction* of the two media concerned. The more this ratio differs from unity, the greater the bending of the ray in passing from one medium to the other. The indices of refraction of some common substances for sodium light (wavelength 5890 A U.), as the light passes from a vacuum into these substances, are given in Table 15.

TABLE 15

ABSOLUTE INDICES OF REFRACTION

Glass, very dense flint	1.71
Glass, light crown	1 51
Rock salt	1 54
Diamond	2 47
Water	1 33
Alcohol	1 36
Carbon bisulfide	1 64
Air	1.000292

All electromagnetic radiation is subject to refraction In Table 16 are given the indices of refractinn of rock salt and fused quartz for various wavelengths in the infrared, visible, and ultraviolet spectral zones.

TABLE 16

INDICES OF REFRACTIONS OF ROCK SALT AND FUSED QUARTZ

Rock Salt

Wavelength	Index of Refraction
1850 A U	1 893
5890	1 544
8840	1 534
11790	1 530
23570	1 526

Fused Quartz

Wavelength	Index of Refraction
1850 A.U	1 574
2144	1 533
2503	1 507
3034	1 486
4046	1 470
5890	1 458
7947	1 453

The fact that light can be refracted makes possible lenses, microscopes, telescopes, and spectacles to correct defects in vision The rainbow is but the dispersion of sunlight into its component colors by the refraction of these component wavelengths to different degrees

C *Diffraction.* If light from a point source passes the edge of a postcard and falls upon a white screen, the shadow of the edge is not sharply defined, but deepens to darkness gradually on one side, and is bordered by very narrnw alternate bright and dark fringes on the other These fringes, due to alternate reinforcement and interference of the radiation from the source by radiation from a new center of wave disturbance, namely, the edge of the card, are known as diffractinn bands. Fig. 58. Another

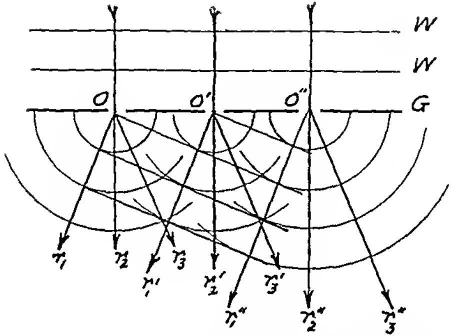

FIG 58 *Diffraction of Light* The diffraction, or apparent bending, of a beam of light can be achieved by means of a so-called diffraction grating One form of grating may consist of a piece of plate glass with many fine parallel lines, several thousand to the inch, ruled with a diamond point across it. G represents such a grating, and W, W sections of plane wave fronts approaching it perpendicularly On passing through the narrow openings between the opaque lines, each wave front will assume a cylindrical form (Huyghen's Principle), and the direction of advance will be the radii of the cylinders, namely, Or_1, Or_2, Or_3, $O^1r^1{}_1$, $O^1r^1{}_2$, $O^1r^1{}_3$, etc Let the arcs drawn from O, O^1, O'' as centers represent new wave fronts at any instant, and let the radial distance between these arcs be equal to the wavelength of radiation of any color There is evidently some direction, in this case Or_1, in which the wave fronts from O will be constantly in advance of the corresponding wave fronts from O^1 by a distance equal to the wavelength Similarly, those from O^1 are ahead of those from O'', etc The series of parallel tangents drawn to these arcs represent the series of plane wave fronts advancing in this direction. In this direction the particular color will be reinforced, and all other colors will suffer whole or partial interference, thus the phenomenon of diffraction can be explained on the basis of interference, as can also the iridescence of soap bubbles, thin films of oil we observe on the roadway, to mention a few of the every day examples of the interference of light

example of diffraction is the concentric bands surrounding the magnified image of a minute particle All radiation consisting of wave trains can be diffracted No further discussion of the phe nomena arising from the interruption of wave trains will be attempted in this discussion, for so far as the therapeutic applica tion of infrared and ultraviolet radition is concerned, no practical use will be made of diffraction

D *Polarization* Radiation, as already stated, consists of a wave train in which vibration occurs in all directions at right an gles to the direction of propagation If a beam of light is reflected from the polished surface of a dielectric such as glass, we will find by suitable examination that a larger part of the reflected beam is vibrating at right angles to the plane of reflection than in that plane A little experimentation will demonstrate that at a certain angle of incidence (the 'polarizing angle," which is different for different dialectrics), the component vibrating in the plane of re flection is practically extinguished all vibration being confined to the plane at right angles to this The light is then plane polarized Fig 59 This effect is more conveniently produced by a Nicol prism or by one of the recently invented polarizing films Such prisms and films polarize by transmission with less loss of light The reduction of glare, due to light reflected from roads, by the wearing of polarizing glasses is a practical application of the phenomenon of polarization In photography use is sometimes made of this characteristic of radiation to achieve stereoscopic views

VIII Transmission and Absorption The transmission of radiation through a substance depends upon the material of that substance and the vibration frequency or the wavelength of the radiation under consideration Materials opaque to visible radia tion may transmit invisible radiation well, and materials that transmit visible radiation readily may be completely opaque, i e, absorb completely, invisible radiation

When radiation impinges upon a substance, a certain part is reflected and a certain part absorbed, with the remainder trans mitted Only that portion which is absorbed can be instrumental

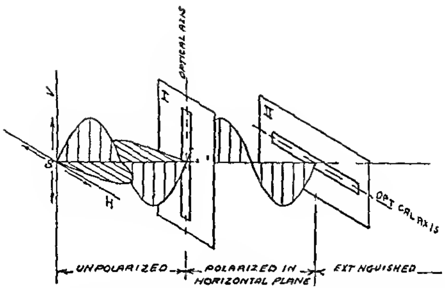

FIG 59 *Polarization of Light* The vibrations of radiation are considered to be transverse that is at right angles to the direction of propagation of the wave If a piece of tourmaline is placed in the path of a beam of light and then a second piece with its axis at right angles to that of the first is placed in the path of the beam transmitted through the first crystal no light will be transmitted that is there will be complete extinction of the radiation If the second piece is now removed and the first rotated through 360 degrees it will be observed if the radiation has not already been polarized that radiation will be transmitted regardless of the position of the axis of the crystal. It is evident then that the vibrating motion must be transverse and in all planes passing through the line representing the direction of propagation

The transverse vibrations can be resolved into vertical and horizontal components In the figure the curves in the horizontal and vertical planes represent respectively the variation in amplitude with respect to time of the summation of all the horizontal components and of all the vertical components of the transverse vibrations The polarizing material I with its optical axis in the vertical position will permit only the vertical component to be transmitted The transmitted beam will now consist of vibrations only in the vertical plane and is said to be polarized in the horizontal plane If a second piece of polarizing material II is placed with its optical axis in the horizontal position at right angles to the optical axis of polarizing material I the vertical component will be absorbed and no light will be transmitted

in bringing about chemical or other effects This is known as the *Grotthus Draper Law*, the first law of photochemistry

A consideration of the curves in Fig 60 shows clearly that for equal intensities of radiation at the depth of 2 cm , the incident intensity would have to be much greater in the case of radiation having the wavelength 12,000 A U than in the case of radiation having the wavelength 10,000 A U Under these conditions, the ratio of depth dose to superficial dose would be considerably greater when using the shorter wavelength In fact, the incident intensity of the radiation of longer wavelength will be approximately 5 5 times that of the radiation of the shorter wavelength in order that water 2 cm from the surface be subjected to the same intensity The ratio of depth dose to superficial dose at the depth of 2 cm would be 0 5 for radiation of wavelength 10,000 A U , and only 0 09 for radiation of wavelength 12,000 A U *

The radiations with which this discussion is chiefly concerned, as already stated, are the infrared and ultraviolet radiations

* Let us calculate first the incident intensity of the radiation of shorter wave length in terms of the incident intensity of the longer wavelength radiation for equal intensities at a depth of 2 cm and then the ratio of depth dose to superficial dose for the two wavelengths of radiation

Let I_0 = incident intensity of radiation of wavelength 10 000 A U
I_0^1 = incident intensity of radiation of wavelength 12 000 A U

I = intensity at 2 cm depth of radiation of wavelength 10 000 A U

and I^1 = intensity at 2 cm depth of radiation of wavelength 12 000 A U

But I^1 = I according to the conditions of the problem.

Now $I = I_0 e^{-0\ 35\times 2}$
and $I^1 = I_0^1 e^{\ 1\ 2\times 2}$ from Lambert's Absorption Law
Therefore $I_0^1 e^{\ 1\ 2\times 2} = I_0 e^{-0\ 35\times 2}$

$$\text{or } \frac{I_0^1}{I_0} = \frac{e^{\ 35\times 2}}{e^{-1\ 2\times 2}} = \frac{e^{\ 7}}{e^{\ 2\ 4}} = e^{+1\ 7}$$

Taking logarithms of both sides of the equation

$$\log_{10} \frac{I^1}{I_0} = 1\ 7 \times\ 434 = 0\ 7378$$

$$\text{Then } \frac{I_0^1}{I_0} = 5\ 47$$

(Footnote continued on next page)

Infrared and the longer visible radiations are absorbed molecularly, that is to say, the energy of such radiations on absorption is imparted to the molecules, resulting in their more rapid motion and hence increased kinetic energy. The consequence is a heating of the absorbing medium. Such radiation is, therefore, referred to as *thermogenic,* or heat generating, radiation The energy of ultraviolet radiation and of the shorter visible radiations, on the other band, is absorbed by the valence electrons of the atoms making up the absorbing substance, and hence is instrumental in bringing about photochemical reactions. Such radiations have dominantly a chemical effect, and are consequently spoken of as *actinic* in their effect

The total radiant energy absorbed by a substance is proportional to the intensity of the radiation entering the medium and the time that the radiation is permitted to enter. If the intensity of radiation is expressed in energy units falling on a square centimeter per second, the total energy falling on that square centimeter in a given number of seconds would be equal to *intensity times seconds;* or total *energy,* E, equals It. This is referred to as the *Bunsen-Roscoe Reciprocity Law,* or the *It law.* If the intensity of the source used should drop off 50 per cent, the same total energy can be applied by increasing the time of irradiation, in this case doubling it If this is expressed in symbols for the sake of brevity, $E_1 = I \times t$ and $E_2 = \frac{\;}{2} \times 2t = It$

$$\text{Therefore, } E_1 = E_2$$

IX INTENSITY AND ITS MEASUREMENT. The intensity of the radiation with which this discussion is primarily concerned is

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(Continuation of footnote)

The ratios of depth dose to superficial dose at the depth of 2.0 cm will be as follows

Wavelength of Radiation	Ratio of Depth Dose to Superficial Dose
10,000 A.U	$I/I_o = I_o e^{-at}/I_o = e^{-.35\times 2} = 0.5$
12,000 A.U	$I^1/I_o^1 = I_o^1 e^{-a_1 t}/I_o^1 = e^{-1.2\times 2} = 0.09$

measured in terms of energy units delivered per unit time per unit area. The erg is the energy unit employed, and is equal to the work done when a force of 1 dyne is exerted through a distance of 1 cm ; the unit area, the square centimeter; and the unit of time, the second The number of ergs delivered per second is usually expressed as microwatts, and the intensity is given as so many microwatts per square centimeter at a given distance from the source

Various types of meters for the measurement of radiation have been devised and are referred to as radiometers Some are selective in their response to radiation, and others are non-selective A radiometer, having a selective response, responds more strongly to certain wavelengths of radiation than to others, whereas a radiometer of the non-selective type responds equally to radiation of all wavelengths throughout the range of wavelengths for which the radiometer is designed Such radiometers give the true intensity of the radiation and not a reading which is indicative of the effectiveness of the radiation in producing the effect upon which the radiometer operates

Intensity readings obtained with a radiometer of either type are useful only for the purpose of comparing similar sources of radiation These readings do not constitute a reliable guide, however, to biologic or therapeutic effects obtainable with the lamps emitting the radiation Obviously, the same number of microwatts per square centimeter could be obtained from both an incandescent lamp and a generator of ultraviolet rays, but without producing the same biologic effects

Further discussion of radiometry is beyond the scope of this book, and the reader is referred to the various works and monographs published on this subject. For less extensive information than given in such standard works but more complete and detailed than can be attempted here, it is suggested that a good encyclopedia be consulted For additional information, prepared in a popular manner on the various other subjects pertaining to the physics of radiation, which perforce must be rather sketchily discussed in this book, a work such as the *Encyclopedia Britannica* may well be consulted.

X INVERSE SQUARE LAW As the distance is increased between ι screen and a source of illumination such as an incandescent amp, the intensity of illumination on the screen decreases rap dly If the distance is doubled the intensity will be found to ιave decreased to approximately ¼, and if the distance is ncreased to 10 times the original distance, the intensity will be

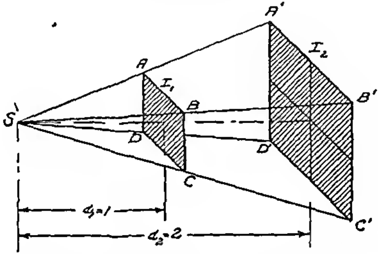


FIG 61 Illustrating the increase of area irradiated and consequent decrease in intensity of radiation as the distance from a point source of radiation to he plane of irradiation is increased The area irradiated is directly propor ional to the square of the distance but the intensity is inversely proportional o the square of the distance Expressed in symbols

$$\frac{I_1}{I_2} = \left[\frac{d_2}{d_1}\right]^2$$

in which I_1 is intensity at distance d_1 and I_2 that at distance d_2

of the order of 1/100 the intensity at the original distance Let us consider the source of light to be a point source In Fig 61, S represents the point source, and A B C D S a rectangular pyra mid, having a base A B C D of unit area at a unit distance from the source Let us now consider the altitude of the pyramid doubled The base of the pyramid will then be the surface A^1 B^1 C^1 D^1, which is at a distance of 2 units from the source The total light flux emitted within the pyramid is now distributed over

an area four times as great as it was when the base was considered to be at unit distance from the source Obviously, as the area over which the light is distributed is increased, the intensity of the illumination decreases, and decreases inversely as the area increases The area intercepted on the plane by the pyramid increases as the square of the distance from the source Hence, the intensity of illumination at any point from a point source of light is inversely proportional to the square of the distance of the point from the source This is known as the *Inverse Square Law* Although it applies only to a point source which is not provided with a reflector, it can be used to approximate roughly the time that should be used for irradiation on increasing or decreasing the distance between the source and the patient For example, if a minimal perceptible erythema is producd by an ultraviolet lamp in 1 minute at a distance of 30 inches the time required for such erythema at a distance of 40 inches would be approximately $\frac{40 \times 40}{30 \times 30} \times 1$ minute, or 1 8, or about 2 minutes

The purpose of this example is to point out that as the distance is increased the time of exposure must be increased to compensate for the reduced intensity The time of exposure must be increased as the square of the ratio of the distances from the source It is suggested that you determine the relative intensity of the lamps you employ at various distances so that you may know whether the inverse square law holds sufficiently close for your lamps to justify its use in estimating treatment time at various distances

XI Cosine Law (Effect of the Obliquity of Irradiated Surface on Intensity of Incident Radiation) If we consider a parallel beam of radiation of uniform intensity impinging normally on a rectangular surface, ABCD, Fig 62, the intensity of the radiation over the irradiated surface, is equal to the total radiant flux Φ divided by the area of the surface on which the flux falls Let us tilt the surface through an angle of Θ degrees, making an angle of (90 O) degrees with the beam of radiation In Fig 62, P

represents the plane of the surface when the surface is at right angles to the beam of radiation; and P^1, its plane when the surface is at the angle of $(90\text{-}\Theta)$ degrees with respect to the beam.

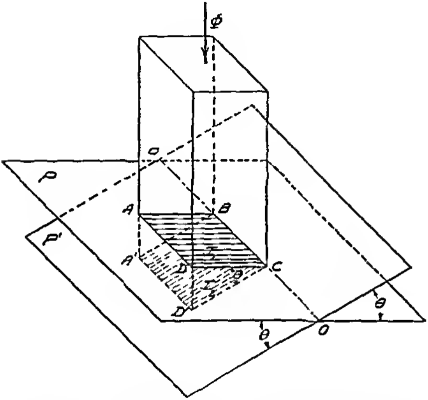


Fig 62 Illustrating schematically the reduction in intensity of radiation due to obliquity of beam. The intensity is proportional to the cosine of the angle Θ, which is also the angle between the beam of radiation and the perpendicular to the plane being irradiated. The relationship between the intensities is known as the *Cosine Law, and is expressed in the form of an equation.*

$$I_2 = I_1 \cos \Theta$$

It is evident that the radiant flux of the beam will now be dispersed over a greater area, A^1 B C D^1, Fig 62. From Fig. 62 it is readily seen that D C and D^1 C are respectively the side adjacent and the hypotenuse of a right triangle having an acute angle of Θ degrees The ratio of the side adjacent to the

hypotenuse of a right triangle is the cosine of the included angle Hence

$$\frac{DC}{D'C} = \text{cosine } \Theta$$

Since the same total amount of radiation falls on the areas represented by A B C D and A^1 B C D^1, it is obvious that the intensity will be greater the smaller the area on which this given quantity of radiation falls If I_1 is the intensity when the surface is at right angles to the beam, I_2 the intensity when it is inclined at O degrees with respect to this position, and Φ the amount of radiation delivered to the surfaces per unit time,

$$I_1 = \frac{\Phi}{(AD) \times (DC)}$$

$$I_2 = \frac{\Phi}{(A'D') \times (D\,C)}$$

$$\text{Therefore } \frac{I_2}{I_1} = \frac{\Phi}{(A'D') \times (D'C)} \times \frac{(AD) \times (DC)}{\Phi} = \frac{(AD) \times (DC)}{(A\,D') \times (D\,C)}$$

$$\text{But since } A'D' = AD \text{ and } \frac{DC}{D'C} = \text{cosine } O,$$

$$\frac{I_2}{I_1} = \text{cosine } O$$

In Table 18 are given the relative intensities for different values of Θ and the corresponding exposure times for the same total radiation per unit area of irradiated surface

When irradiating a patient, the beam of radiation should be so directed that the impinging rays will strike the surface as nearly perpendicularly as possible However, the error in exposure time is not excessive if no compensation is made for decreased intensity, so long as the deviation of the beam from the perpendicular to the irradiated surface does not exceed 30° For a 30° deviation from the perpendicular, corresponding to an angle of 60° between the surface and the beam of radiation, the exposure

would have to be increased only 15 per cent. If the desired degree of erythema is obtained in 1 minute with the beam impinging at right angles to the surface, an exposure time of one minute and 9 seconds would produce the same effect if the lamp is in-

TABLE 18

Deviation of Beam From Perpendicular ($\theta°$)	Relative Intensity (I)	Relative Exposure Time (t)	Exposure Time, if Time is 1 Minute When Beam is Perpendicular
0	100%	100%	1 0 min
30	86 6	115	1 min 9 sec
45	70 7	141	1 min 25 sec
60	50	200	2 min
90	0	∞	∞

clined so that the beam impinges at 60° with respect to the surface. A difference of 9 seconds does not seem of great enough significance in the case of ultraviolet irradiation to warrant making corrections for deviation of the beam from the perpendicular In practical application, direct the beam as nearly perpendicular to the surface to be irradiated as you can judge, without making actual measurements; then any error that might be introduced will be negligible.

PART C RADIATION

SECTION TWO THERMOGENIC RADIATION

I DEFINITION The term *Thermogenic Radiation* will be used to describe heat producing radiation By derivation it means heat producing In our opinion it is to be preferred to such terms as phototherapy, radiant heat therapy, infrared therapy, and the vague misnomer "deep therapy," for the term *thermogenic radiation* is inclusive of all radiation which is productive of heat within tissues, furthermore, the term is definitely descriptive of the effect such radiation produces, namely, the generation of heat

Thermogenic radiation may then be defined as radiation which, on absorption, is transformed into heat within the absorbing medium Such radiation, as already stated, is absorbed molecularly Its energy is utilized in increasing the rapidity of motion of the molecules of the absorbing body, and so their kinetic energy The heat energy possessed by a body depends upon the kinetic energy of its particles Therefore, the absorption of radiant energy which increases the kinetic energy of the molecules results in an increase of heat energy in the absorbing body, with proportionate increase in temperature Whether the rate of rise in temperature is directly proportional to the rate at which energy is absorbed, depends upon the rate at which heat is lost from that body The temperature, however, will rise until the rate of heat loss equals

the rate of heat generation This suggests that to produce maximum temperature rise in tissue, if such is desired, steps should be taken to minimize the rate at which heat is lost. For that reason a lamp generating thermogenic radiation is frequently draped as shown in Fig. 63 By this means the irradiated area will be subjected to air having a temperature sufficiently high to reduce

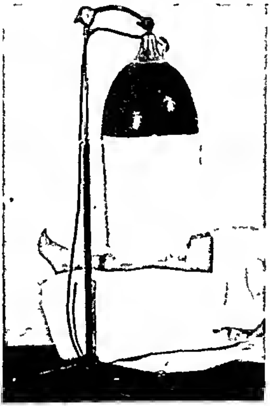


Fig 63 Administration of thermogenic radiation
Illustrating method of reducing heat loss

loss of heat from the skin by convection currents of cool air; furthermore, it insures that the air in contact with the irradiated skin will he sufficiently saturated with moisture to reduce evaporation of perspiration and consequent cooling of the skin and the blood in the capillaries.

Thermogenic radiation comprises the infrared portion of the electromagnetic spectrum and the longer visible rays

A Infrared Infrared radiation, as used therapeutically extends from the limit of the visible zone, having a wavelength of approximately 8000 A U, to about 150,000 A U Therapeutic infrared radiation is subdivided into two spectral zones, one designated the *near infrared* and the other the *far infrared*

1 *Near Infrared* The near infrared zone extends from 8000 A U, the limit of the visible spectrum, to 15 000 A U

2 *Far Infrared* The far infrared extends from 15,000 A U to 150 000 A U The marked absorption of wavelengths beyond 15 000 A U by water, suggests 15,000 A U as a reasonable point of division between the near and far infrared radiations

B Visible Visible radiation that is thermogenic in effect, extends from the limit of the red rays, having a wavelength of 8000 A U, down through the red and possibly including the orange and yellow So far as conclusive evidence is concerned, either experimental or clinical, the only effect of the long visible rays seems to be the production of heat, and consequently such rays are employed for that purpose in medicine However the fact that these vibration frequencies give rise to visual color sensations indicates that such wavelengths of radiation produce chemical effects, for it is through the chemical effect of radiation on chemical substances in the retina that visual sensations are stimulated Therefore, it may be that visible radiation is not completely absorbed molecularly by tissue with resultant heat generation therein, but that a portion is absorbed by the valence electrons of light sensitive substances which may be present, giving rise to chemical effects It may be that further investigation will definitely establish whether visible radiation, on absorption by tissue has only a heating effect or has, in addition, photochemical effects which may be useful in the treatment of certain conditions On the basis of present evidence, however, we in this discussion shall assume that the only effect is thermal, and shall give technics of application based on that assumption

II *Generation* Sources of thermogenic radiation fall into two classifications luminous and non luminous, depending upon whether or not there is present a component of visible rays in

the range of wavelengths of radiation emitted by the source. Let us consider, first, non-luminous sources.

A. *Non-luminous Radiators* As already stated, such radiators emit radiation which does not have a component of visible radiation They consist of heated bodies. Such heated bodies may consist of resistance wire, wound into appropriately shaped coils, Fig 64, of resistance wire covered with copper tubing or with other metal, Fig. 65; or with carborundum or some other refractory material, Fig. 66 These coverings, if highly conductive electrically, must be electrically insulated from the coils of the resistance wire to prevent short circuiting, either by air, or by such materials as are electrically insulating, or relatively poor electrical conductors, but still relatively good thermal conductors When air is used as an insulator between the coil of resistance wire and the cover, the cover obviously is not heated by conduction but by the absorption of radiant energy which is emitted by the electrically heated coil and transmitted through the layer of air The resistance wire serves merely as a heater when a covering is employed The covering, which is heated by the resistance wire, is the source of the radiation.

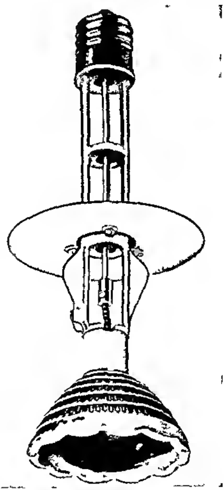


FIG 64 Element consisting of resistance wire, emitting dominantly far infrared radiation

The amount of wattage, dissipated in the resistance wire, will determine whether the source is to be classified as non luminous or luminous The radiators illustrated in Figs 64, 65, and 66 are usually operated at such power consumption that they are heated

FIG 65a. Element consisting of resistance wire covered with copper tubing which is separated from the coil of resistance wire by appropriate insulation emitting dominantly far infrared radiation (Calrod Unit)

FIG 65b Radiograph showing construction of the Calrod Unit.

sufficiently high to emit some visible radiation However, the emission from these sources is dominantly non luminous, and so it has become customary for many to refer to such sources as *non-luminous*, in contradistinction to brilliantly luminous sources

such as incandescent lamps However, by operating these radiators at a lower wattage, the emission from them can be restricted to the longer non luminous wavelengths Under such conditions of operation, they are true non luminous sources of thermogenic

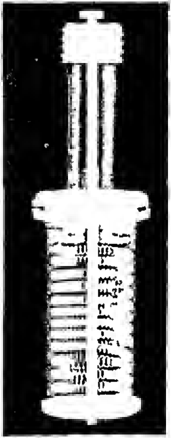


FIG 66a. Element consisting of resistance wire embedded within carborundum, *emitting dominantly far infrared* radiation (Zoalite Unit)

FIG. 66b Radiograph *showing construction of* Zoalite Unit.

radiation The terms *luminous* and *non luminous* are objection able As will be brought out in subsequent paragraphs, the terms *far infrared* and *near infrared* are to be preferred for designating the type of radiation emitted by various sources of thermogenic radiation

All bodies having a temperature above absolute zero, which is the temperature at which theoretically all molecular motion ceases emit radiation The intensity of the radiation, and the range of wavelengths emitted, are dependent upon the temperature of the radiating body Let us assume a body which will absorb all radiation that falls upon it and will reflect none Such a body must be black in color and possess a zero reflection coefficient for all wavelengths of radiation This theoretical body is called a *perfect black body* Such a body is a highly efficient emitter of radiation It has been found that the total rate of emission from such a body is proportional to the fourth power of its absolute temperature (*Stephan Boltzmann Law*) * The absolute temperature of the body equals its centigrade temperature plus 273° This absolute tem

* *Stefan Boltzmann Law* The relation that total emission rate is proportional to the fourth power of the absolute temperature is known as the *Stefan-Boltzmann Law* and is expressed in the form $E = KT^4$ in which E is the emission in ergs per second per square centimeter of radiating surface T the temperature of the radiating body in degrees Kelvin and K a proportionality constant called the Stefan Boltzmann constant Strictly speaking the foregoing relation holds only when the temperature of the surrounding surfaces is at absolute zero Taking into consideration the fact that these surrounding surfaces are at some temperature T_0 above absolute zero the relation is expressed as follows $E = K(T^4 - T_0^4)$

If the body is not a perfect or black body radiator a term must be introduced in this relation representing the emissivity of the body Letting e_t be the emissivity of the radiator the equation is now written

$$E = K(T^4 - T_0^4)\, e_t$$

The emissivity e_t depends on the nature of the radiator and is influenced somewhat by temperature For a perfect or black body radiator it is unity and approaches unity for rough surfaces In the following table are given values of e_t for a number of metals

Metal	Total Emissivity e_t at		
	1000 K	1500 K	2000 K
Tungsten	0 114	0 192	0.260
	200 K	400 K	600 K
Oxidized Aluminum	0 113	0 153	0 192
Oxidized Copper	0 568	0.568	0 568
Oxidized Cast Iron	0 643	0 710	0 777
Oxidized Nickel	0 369	0 424	0 478

(Footnote continued on next page)

perature is usually referred to as its temperature in degrees Kelvin, written T° K.

The law discussed in the previous paragraph shows how much energy is radiated at a given temperature but it does not give any information regarding the spectral distribution of the radiant energy. The energy radiated in any wavelength interval is given by a law known as *Planck's Radiation Law.** In Fig. 67 are plotted the calculated spectral energy distribution curves of a black body radiator for the absolute temperatures of 1000° K, 2000° K, and 3000° K for equal total emission of radiant energy of all wavelengths.

(Continuation of footnote)

If T is greater than 4 T_0, the error introduced by neglecting T_0 is less than 0.5 per cent, and the Stefan Boltzmann Law may be stated in the convenient form: $E = KT^4 e_t$, in which $K = 5.7 \times 10^{-5}$ ergs per sec. per cm.² per deg.⁴

Substituting the value for K and converting ergs per second into watts (10^7 ergs per second = 1 watt), we have

$$E = 5.7 \times 10^{-12}\, T^4 e_t \text{ watts per square centimeter.}$$

Example. Let us determine the emission in watts per square centimeter of a tungsten radiator heated to a temperature of 1000° K

$$E = \frac{5.7 \times 1000 \times 1000 \times 1000 \times 1000 \times 0.114}{1{,}000{,}000{,}000{,}000}$$

$$= 65 \text{ watts per square cm.}$$

If the temperature of the radiator is increased to 1500° K, the emission will become

$$E = \frac{5.7 \times 1500 \times 1500 \times 1500 \times 1500 \times 0.192}{1{,}000{,}000{,}000{,}000}$$

$$= 5.53 \text{ watts per square centimeter}$$

Therefore, by increasing the absolute temperature 50 per cent, the emission is increased $\frac{5.53}{0.65} = 8.5$, or more than 8 fold.

* *Planck's Radiation Law* After substituting appropriate numerical values in this law, the following equation is obtained

$$E_\lambda d\lambda = \frac{(3.732 \times 10^{-12})\, \lambda^{-5}}{2.718^{\frac{1.436}{\lambda T}} - 1};$$

where $E_\lambda d\lambda$ = energy radiated in the wavelength interval $d\lambda$ in watts per square centimeter of radiating surface; λ = wavelength in centimeters, and T = absolute temperature in degrees Kelvin.

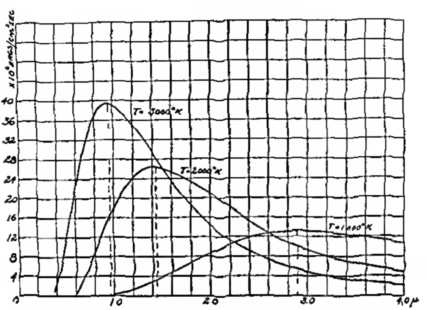


FIG 67 Calculated spectral energy distribution curves of a black body at different temperatures for equal total emission of radiant energy of all wavelengths

The radiation emitted by a hot body, as shown by Planck, is composed of radiation of various wavelengths If the intensity of these radiations is measured and plotted against wavelength, a curve will be obtained whose shape is characteristic of all hot body radiators This curve, representing the spectral distribution of energy emitted by a hot body, always has a maximum at some particular wavelength As the temperature of the radiator is increased, the wave length at which the maximum emission of energy occurs is decreased A definite relationship has been found to exist between the wavelength at which the maximum emission occurs and the absolute temperature of the radiating body This relationship is known as *Wien's Displacement Law* *

In Table 19 are given the wavelength at which maximum emis

* *Wien's Displacement Law* If λ_m is the wavelength in microns at which maximum intensity of emission occurs and T is the absolute temperature in degrees Kelvin of the radiating body (black body),

$$\lambda_m T = 2884$$

sion occurs, and the intensity of radiation at this wavelength for the black body radiators whose spectral distribution curves are given in Fig. 67. The per cent of the total energy emitted in the spectral zone extending from 5000 A U., or 0 5 microns, to 16,000 A U., or 1.6 microns, is also given This spectral zone encompasses the range of wavelengths which will be shown to have maximum penetration into tissue

TABLE 19

Temperature of Black Body Radiator	Wavelength at Which Maximum Emission Occurs	Intensity in Micro-ergs per sq cm. per sec at This Wavelength	Per Cent of Total Radiation Emitted in Zone $\lambda = 5000$ A U to $\lambda = 16000$ A.U
1000° K	28840 A U	13 0	2 5
2000° K	14420 A U	26 4	30 3
3000° K	9613 A U	39 4	50 5

B. *Luminous Radiators* From a consideration of the spectral energy distribution curves in Fig 67, it is evident that a black body at the temperature of 1000° K emits no appreciable radiation in the visible zone, 4000 A U to 8000 A U Hence, it may be considered a nonluminous source, that is, a source which emits no radiation that stimulates the sensation of vision

A black body at temperature 2000° K does, however, emit radiation in this zone, and must, therefore, be classed as a luminous source, although the amount of energy emitted in the visible zone is much less than the output of invisible infrared radiation.

At 3000° K a radiating body would appear white hot. Such a radiator emits a relatively large percentage of its total radiation output in the visible zone of radiation.

The latter two radiators are luminous radiators. From a consideration of the percentage of total radiation output emitted in the zone of maximum penetration into tissue, that is, the percentage of the total radiation emitted in the spectral zone, 5000 A U to 16,000 A U., the more luminous sources are obviously to be preferred as generators of thermogenic radiation for therapeutic use A black body at the temperature of 3000° K is clearly a more

efficient generator of the desired thermogenic radiation than are those at the temperatures of 1000° K and 2000° K

A metallic body however, could not be heated to this temperature in the open air without complete oxidation and burning up Therefore, it is necessary to select a metallic substance that has a high melting point and to heat that substance to the desired temperature in an evacuated glass bulb, or in a glass bulb containing an inert gas such as nitrogen or argon The ordinary incandescent lamp having a filament of tungsten and filled with an inert gas provides, therefore, an ideal source of thermogenic radiation of the preferred wavelengths

Referring to Fig 67, the spectral energy distribution curve for a black body at the temperature 3000° K may be taken as representing approximately that obtained from a tungsten filament lamp, and the spectral distribution curve of a black body at 2000° K as representative of a carbon filament lamp The carbon filament will emit about 30 per cent of its total radiant energy in the desired spectral zone whereas the tungsten lamp will deliver 50 per cent of its output in this preferred spectral region, as indicated in Table 19 The carbon filament lamp may produce a greater sensation of superficial heat than the tungsten filament lamp, but this is due to the fact that a greater proportion of its total output lies in the far infrared zone Far infrared radiation penetrates but slightly into tissue, it is absorbed and transformed into heat in the superficial tissues, where the endings of nerves responding to heat and cold lie

Some are under the impression that various colored bulbs may have certain specific effects There is no evidence supporting such a view Glass bulbs of various colors which have specific absorbing properties that will reduce intense glare, without too great a sacrifice of radiant energy in the zone of preferred wavelengths may at times be used advantageously The use of various filters in conjunction with a tungsten filament lamp will be discussed in the following paragraphs

III Transmission and Absorption Radiant energy does not produce an effect unless it is absorbed A knowledge of the trans

mission and absorption characteristics of certain substances, therefore, are of the greatest importance as a guide in the intelligent use of radiation for therapeutic purposes Of these substances, water is one of the most important, for water constitutes about 80 per cent of living tissues and its transmission and absorption

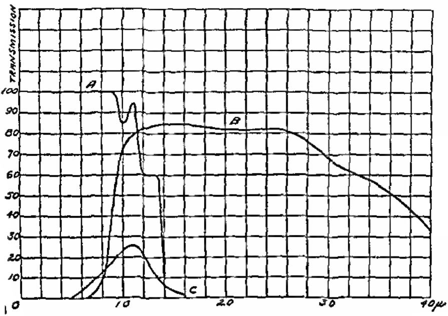


FIG 68 Transmission of radiation by various substances A 4 mm of water B Corning glass, No 254, 1 mm. thick. C. Human cheek.

characteristics must therefore have an important effect on the transmission and absorption of radiation by living tissue Measurements of the transmission of radiation by 4 mm. of water,[1] by the human cheek,[2] and by Corning glass No 254, 1 mm in thickness,[3] are given in Fig 68

The transmission curve for the human cheek shows that the thermogenic radiation which penetrates relatively deeply into

[1] Luckiesh, M : Sources of Visible and Infrared Radiations for Deep Therapy Journal of the Franklin Institute Vol 207, No 1 (Jan) 1929

[2] Cartwright J Optic Soc America 20 83 (1930)

[3] Handbook of Chemistry and Physics, 23rd Edition Chemical Rubber Publishing Co , Cleveland, 1939

tissue, lies in the spectral zone 5000 A U to 16,000 A U A source, therefore, which delivers a high percentage of its radiation in this zone, should produce a relatively high ratio of subcutaneous heating to skin surface heating

The percentages of the incident radiant energy from various sources which penetrate to a depth of 1 mm and 1 cm in tissue as given by Forsythe and Christison* are recorded in Table 20

TABLE 20

	Iron Heater (1000° K)	Carbon Filament Lamp (2150° K)	Tungsten Filament Lamp (2970° K)	Sun
1 mm Flesh	0 58%	15 0%	30 0%	29 0%
1 cm Flesh	0 02	0 9	1 9	2 3

Further increase in subcutaneous heating, in comparison with skin heating, can be obtained by eliminating the longer infrared wavelengths beyond 15 000 A U This can be achieved by using a water cell in conjunction with a high wattage tungsten filament lamp The intense visible light from such a lamp may, under certain conditions, be objectionable In such case, the visible radiation can be eliminated by the use of a 1 mm filter of Corning glass No 254, known as a heat transmitting filter The addition of such a filter would decrease the radiation in the desired zone of wavelengths about 35 per cent When such a filter is employed, means must be provided to cool the filter

Tungsten filament lamps of various wattages are used clinically The wattages are commonly 500, 1000, and 1500 Where a bat tery of lamps is used, the lamps may be of 60, 100, or 200 watts each The type of radiation obtained from tungsten filament lamps, so far as the range of emitted wavelengths is concerned, is the same regardless of the wattage consumed by the lamps, so long as the temperature of the filaments remains constant

* Forsythe W E Christison F Ultraviolet Radiation from Sun and Heated Tungsten J Optic Soc America 20 396-410 (July) 1930

The intensity of the radiation will, however, be greater with the higher wattages If, however, a 1000 watt tungsten filament is operated at 50 per cent of its rated voltage, and hence at a markedly lower wattage, the type of radiation will be altered, for the temperature of the filament will then be at a reduced level with consequent increase in the long wave infrared component of the emitted radiation.

Lamps rated at different wattages have filaments of such dimensions that the lamps, when operated at their rated wattages, emit radiation of the same spectral distribution.

IV. Relative Heating by Various Sources. The measurements of transmission of thermogenic radiation through the human cheek, presented in the preceding discussion, show that maximum penetration occurs at a wavelength of about 11,000 A.U. *Wien's displacement law* may be employed to determine the approximate temperature of a radiating body which has its maximal emission at the wavelength of 11,000 A U or 1.1 microns. We find that the absolute temperature of such a radiator must be

$$T = \frac{2884}{\lambda_m} = \frac{2884}{1\,1} = 2620^\circ \text{ K}$$

The tungsten filament of the ordinary incandescent lamp used for lighting purposes, when provided with its rated voltage, operates at a temperature of about 2900° K. Hence, such a lamp should be an excellent source of penetrating thermogenic radiation In Fig. 69 is given the spectral energy distribution curve of a tungsten filament lamp, both with and without a water filter. A water filter, as was shown in a preceding paragraph, absorbs strongly those wavelengths which have but slight penetrating power into tissue, and which therefore heat chiefly the skin. By using a water cell in conjunction with an incandescent lamp, these longer radiations which produce heating primarily of the skin, can be eliminated. Thus greater exposure, with consequent greater heating of the subcutaneous tissues, will be tolerated by the patient.

In Fig 69 are also given the curves of spectral energy distribution from an incandescent lamp, with and without a water filter, after having been transmitted through the average human cheek. In each case, the amount of energy remaining unabsorbed after traversing this thickness of tissue, is proportional to the area included under the distribution curve

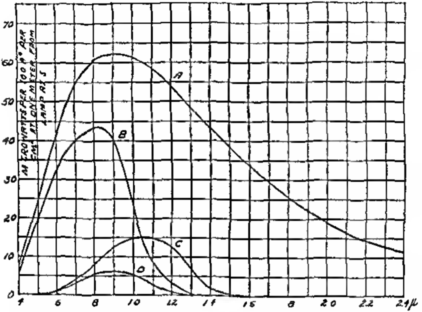


FIG 69 Spectral energy distribution of a tungsten lamp taking 6 42 amperes at 110 volts A. In air B In water cooled unit with filter of circulating water C Curve A after transmission through cheek (computed) D Curve B after transmission through cheek (computed)

It is evident from Fig 69 that the ratio of energy unabsorbed after transmission through the average cheek to the total incident radiation, is considerably greater when a water filter is employed The water filter effectively absorbs the long infrared radiation which is not transmitted by tissue, but which is absorbed and transformed into heat in the upper layers of the skin producing excessive skin heating without appreciably affecting the subcutaneous tissues The advantages of a water filter are two fold

1. The elimination of non-penetrating, skin irritating, far infrared radiation.

2. The possibility of close application of the source to the part treated with a corresponding high intensity of penetrating thermogenic radiation; such penetrating radiation produces maximum heating of the subcutaneous tissues with minimum heating of the skin, and hence with minimum discomfort to the patient.

Actual measurements have been made of the temperatures obtained in tissue irradiated by various sources of thermogenic radiation having different spectral distributions Sonne[3] showed experimentally that with a luminous source, greater *depth of heating can be obtained* than with a relatively low temperature source of infrared radiation His data are presented in Fig 70

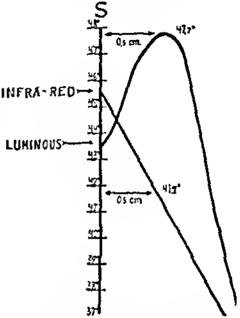


FIG 70 Temperature of the skin and subcutaneous tissues when irradiated with luminous and infrared rays (From Sonne, Carl Investigations on the Action of Luminous Rays and Their Mode of Action Archives of Physical Therapy, X Ray, and Radium, Vol 10, p. 93, March, 1929)

The temperature curves in Fig 70 show that at a depth of 0 5 cm. a temperature of 47.7° C was obtained with a luminous source, which emits strongly in the near infrared zone, for a skin temperature of 43.5° C; whereas, at that depth a temperature of only 41 7° C was obtained with a source emitting principally far infrared radiation for a skin temperature of 45 5° C.

[3] Sonne, Carl *Investigations on the Action of Luminous Rays and Their Mode of Action* Arch Phys Therapy, X ray, and Radium. Vol 10, No 3, p 93 (Mar) 1929

Hardy and Muschenheim [*] using radiation of wavelength 12,000 A U, determined the penetration of such radiation into dead

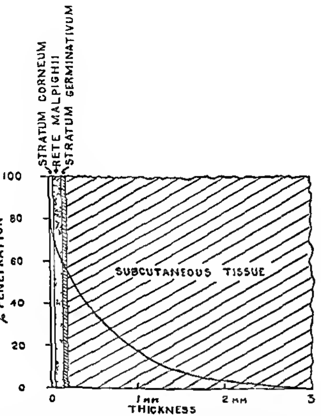


FIG 71 Schematic diagram showing absorption of infrared rays of the most penetrating radiation ($\lambda = 1.2$ microns) by dead tissue According to Hardy and Muschenheim blood in living skin would cause a much more rapid extinction (From Hardy and Muschenheim Radiation of Heat from the Human Body Transmission of Infrared Radiation Through Skin. Journal of Clinical Investigation 15 1 (Jan) 1936)

tissue In Fig 71, taken from their publication, is given the per cent penetration of radiation at various depths below the skin

[*] Hardy J D Muschenheim C Radiation of Heat from the Human Body, Transmission of Infrared Radiation Through Skin J Clin Investigation 15 1 9 (Jan.) 1936

surface. In the first three layers of the skin, the stratum corneum, the rete malpighii, and the stratum germinativum, more than 40 per cent of the incident intensity is absorbed, leaving about 60 per cent to be absorbed in the subcutaneous tissues At a depth

TABLE 21

COMPARATIVE TEMPERATURE MEASUREMENTS TAKEN AT A DEPTH OF TWO INCHES IN THE THIGH OF A SUBJECT

Subject	Incandescent Lamp with Water Cell Filter		Incandescent Lamp Without Water Cell Filter	
	Initial	Final	Initial	Final
1	100 1° F	100 7° F	100 0° F	100 1° F
2	100 0° F	100 7° F	100 0° F	100 0° F
3	100 0° F	100 9° F	99 7° F	100 0° F
4	100 2° F	100 7° F	99 9° F	100 0° F
5	99 3° F	100 6° F	99 3° F	99 6° F
6	98 4° F	100 6° F	99 3° F	100 9° F
Average Temperature Rise	1 1° F		0 4° F	

of one millimeter below the surface of the skin, there remains unabsorbed less than 20 per cent of the incident radiation.

Our own hitherto unpublished data on the relative heating produced in tissue by an incandescent lamp, with and without a water filter, are given in Table 21

The temperature measurements were made by means of thermocouples introduced into the thigh through a canula. Both lamps, having the same wattage consumption, were placed as close to the skin surface as tolerance would permit The lamp without a filter was placed an average distance of 8 inches from the skin, while the lamp with a water filter was almost in contact, with only sufficient spacing to prevent cooling of the skin by conduc-

tion to the relatively cool water cell All six subjects were quite uncomfortable when the lamp without a filter was used, but were without the least discomfort when the lamp with the water filter was employed The thigh was exposed to the radiation for a period of twenty minutes The average temperature increase, as can be seen from the table, was greater with the lamp equipped with the filter

By eliminating the long wavelength infrared radiation by means of the water filter, it was possible to bring the source of radiation very close to the skin without intolerable production of heat in the superficial tissues The radiation transmitted through the water cell was of wavelengths that penetrate well into tissue In the case of the unfiltered lamp, a distance of 8 inches between the skin and the source had to be maintained in order that the patient could tolerate a 20 minute irradiation, whereas the filtered source could be placed practically in contact with the skin The advantage of using a water filter is evident If we assume that energy absorption was the same per unit volume of skin per unit time for the two sources (i e , tolerance dose), the ratios of depth dose to skin dose for the filtered and unfiltered source should be approximately as $\frac{1\ 1}{0\ 4}$ or 2 75 In other words, if an unfiltered incandescent lamp produces a given depth heating when operated at patient's skin tolerance, the same degree of depth heating could be achieved with a water filtered incandescent lamp at about 36 per cent of the skin tolerance dose

V PHYSIOLOGIC EFFECTS The immediate effect of the absorption of thermogenic radiation by tissues is the production of heat Whether or not there will result any marked elevation in the temperature of the tissues, will depend upon the ability of the tissues to dissipate the heat generated Temperature will be elevated if the rate of heat generation exceeds the maximum rate at which the tissue can dissipate the heat Such an effect results when the rate of heat input is relatively low and the physiologic response is impaired, or when the rate of heat input is high and

the physiologic response is normal. Therefore, the intensity of radiation to be employed in various conditions is determined by the degree of impairment of the heat dissipating power which is present. In the treatment of certain peripheral vascular diseases by thermogenic radiation, great care must be exercised in order to avoid excessive heating due to the impaired circulation and the consequent inability of the tissues to dissipate heat readily.

Temperature measurements indicate the intensity of heat at any given point. The heat capacity of the tissues will determine the number of calories required to produce any change in temperature. The heat capacity of tissue is high, requiring 1 calorie to raise 1 gram of tissue 0 8° C or 1 44° F Like water, of which they largely consist, tissues can absorb considerable quantities of heat with comparatively small changes in temperature The thermal capacities of different tissues are not identical, and in any given tissue, variations will occur with vascular changes

The vascular system plays an important role in the conduction of heat; it serves to prevent great differences in the temperature of the different parts of the body It permits tremendous variations in the thermal conductivity of such tissues as the subcutaneous fat and probably the dermis Hence, such tissues may serve as good thermal insulators on exposure to cold, and yet not interfere to any great extent with heat loss under warm conditions. These marked variations in thermal conductivity with degree of vascularity must be considered when heat is used as a therapeutic agent *

A. *The Effect of Temperature on the Vasomotor Apparatus* Lewis and Grant[7] have shown that temperature variations may modify not only vasomotor tone but also reactions to stasis They consider these alterations as probably due to some chemical change such as the production of a histamine-like substance However-

* An effect frequently observed after prolonged and repeated exposure to infrared radiation of relatively high intensity is a mottled type of erythema followed by a similar type of pigmentation This type of erythema, due to heat, is called *erythema ab igne*

[7] Lewis, T, and Grant, R T Vascular Reactions of the Skin to Injury Heart 11 209 (May) 1924

ever, Austin and Cullen[8] have demonstrated that temperature changes produce profound alterations in the acid base equilibrium of the blood It therefore remains questionable whether such acid base changes in the blood or tissues might not account for some of the vascular changes ascribed by Lewis to a histamine like substance, even though the latter may be involved when the temperature changes are injurious Concerning the effects of thermogenic radiation, Hardy and Muschenheim[9] state

As the infrared radiation is wholly absorbed near the surface by both living and dead tissue, the therapeutic benefits from such rays must be provided by some peripheral mechanism The therapeutic effect of these rays is well known, but inasmuch as 50 per cent of the radiation passes through the stratum germinativum, it is possible that some chemical action may be stimulated by these rays in these very important lower skin layers. In any case the hope of reaching deep tissue with these rays is rather a vain one

When heat is used, the blood vessels become dilated and blood flow is increased The rapid circulation increases the thermal conductivity of the tissues and distributes the heat over a very large area, in fact through the whole body, and thus retards the rise in local temperature In contrast, cold reduces the circulation and a marked fall of temperature of the part subjected to cold can occur Therefore, when a local rise of temperature in an extremity is desired and general systemic effects are contraindicated, the latter may be avoided to a large extent by immersing one of the other extremities in moderately cold water, thereby facilitating heat loss

The typical response to temperature changes is a vasodilatation to warmth and a vasoconstriction to cold The arterioles, the capillaries, and the veins are involved, and the response results in a considerable local increase or decrease in the blood flow to the

[8] Austin J H and Cullen G E Hydrogen Ion Concentration of the Blood in Health and Disease Medicine 4 275 (August) 1925

[9] Hardy J D and Muschenheim C Radiation of Heat from the Human Body V The Transmission of Infrared Radiation Through Skin J Clin Investigation 15 1 (Jan.) 1936

part treated These changes are partly effected through nervous reflexes, and consequently may involve distant areas not primarily affected by the temperature change The work of Lewis and Grant[10] *suggests that reflex vasodilatation to warmth, at a distance*, is entirely dependent on the sympathetic nerve supply of the area involved An increase in surface temperature from 78 8° F to 107 6° F increases the rate of blood flow some five to six times A decrease in surface temperature below 64 4° F increases the flow in superficial skin vessles, but such increases are overbalanced by decreases in flow in the deeper vessels

B *Effect on Capillary Pressure and Fluid Interchange* Temperature changes have considerable effect on capillary pressure and consequently on the formation of tissue fluid This fluid ultimately may leave the part as lymph The hypothesis has been advanced that fluid interchange between the blood and the tissue fluids depends normally on a simple physical balance between the hydrostatic pressure of the blood in the capillaries (a pressure which tends to filter fluid) and the osmotic pressure of the protein colloids, which, unable themselves to pass the capillary wall exert an attractive force on watery solutions of diffusible substances This hypothesis has been supported by experimental evidence presented by Landis,[11] who has demonstrated that the rate of fluid transfer is linearly proportional to this pressure difference There appears little doubt that there is a transference of fluid from the blood stream, and that consequently formation of lymph must be greatly increased by a rise in temperature McMaster[12] has demonstrated this by injecting *patent blue V* into the skin of the volar surface of both arms One arm was used

[10] Lewis T and Grant R T Observations Relating to the Influence of the Cutaneous Nerves on Various Reactions of the Cutaneous Vessels Heart 14 1 1927

[11] *Landis E M The Relation Between Capillary Pressure and the Rate at* Which Fluid Passes Through the Walls of Single Capillaries Am J Physiol 82 217 (October) 1927

[12] McMaster P D Changes in the Cutaneous Lymphatics of Human Beings and in the Lymph Flow Under Normal and Pathological Conditions. J Exper Med 65 347 (March) 1937

as a control, and to the other heat was applied The lymphatic capillaries of the treated arm appeared slightly wider Dye entered these lymphatics much more readily and seemed distributed farther in them for the area of diffusion of the dye was observed to be greater Furthermore, the network of lymphatics seemed more densely injected Moreover, the dye escaped from the capillaries more rapidly When, owing to a damaged capillary wall, protein has left the blood stream and has reached the tissue spaces, it is probably returned normally to the circulation by the lymph stream The work of McMaster indicates that heat may be of assistance in expediting this exchange

C *Effect of Temperature on Acid Base Equilibrium* Changes in temperature have a profound effect on the blood When blood is warm the dissociation constants of the acid radicals of the proteins are increased to a much greater extent than is that of carbonic acid In consequence, if blood is warmed under conditions where the total carbon dioxide content is constant, the proteins combine with much base, previously in the form of sodium or potassium bicarbonate The carbon dioxide thus freed is added to the free carbonic acid originally present, the acidity is greatly increased and the carbon dioxide tension is raised These changes resulting from temperature elevation, are great, producing a change in the acidity of blood comparable to the normal difference in acidity between arterial and venous blood

D *Effect of Temperature on Venous Blood* The ratio of CO_2 to O_2 present in the blood is affected by temperature, and is dependent upon the balance between blood flow and tissue metabolism On exposure to extreme cold the blood flow may be very slow and yet the loss of oxygen in the superficial tissues may be slight, since metabolism of these tissues may have been reduced almost to zero At slightly higher temperatures the energy metabolism will be increased without a corresponding increase in the blood flow Under such conditions, a considerable proportion of the oxygen will be removed At the temperature of 107 6° F to 113° F, inflammation increases the blood flow to such an extent that, in spite of a relatively high metabolism, venous blood from skin areas may be indistinguishable from arterial

blood However, it must not be overlooked that, with an increase in circulation, the tissues are exposed to more blood per unit of time In spite of the great changes in the venosity of the blood, the direct effects of temperature rise are more important than the blood changes. Such direct effects are a probable increase in the activity of leukocytes in phagocytosis, and an increase in the velocity of the blood flow which reaches a maximum at approximately 104° F On the other hand, phagocytosis is delayed in areas exposed to local cooling

E *Effects of Temperature on Tissue Metabolism* A change in temperature has a definite effect on the metabolism of tissues Where this effect may be observed on isolated organs or on small cold blooded organisms, the metabolic rate is found to increase two or three times for a rise of 18° F The change in metabolic rate, due to temperature change, has an important influence on the activity of tissues In addition there are direct effects of temperature changes which may modify markedly the activity of tissues, especially the functioning of the skin and the muscles The warming up of an athlete before a race is a case in point, the fact that warm weather is usually considered the best time for sprints supplies another example Conversely the numbness of the surface and the partial paralysis of peripheral muscles, which become capable of only very slow movements in subjects exposed to cold, is a further example

These direct effects, however, often are not demonstrable in the total metabolism, since they are offset by direct reflex effects In warm blooded animals the direct effects of temperature are offset by reflex effects On exposure to cold, the metabolism of certain parts may be lowered, while that of others may be increased to a degree more than sufficient to counterbalance the decrease Only after prolonged exposure to cold with the fall of the body temperature as a whole and with depression of the nervous reflexes, can a marked decrease in general metabolism be demonstrated When an increase in metabolism is demonstrable after exposure to cold, it is mainly muscular in origin, and is brought about by shivering or by the adoption of voluntary muscular movements by the individual The metabolic increase result

ing from shivering may be as great as 100 to 300 per cent. The muscles probably are contracting under conditions in which their mechanical efficiency is particularly low, and their efficiency as heat producers high

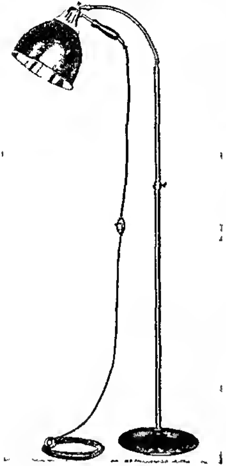


Fig 72 Infrared lamp with element illustrated in Fig 64, page 197

In estimating the value of heat in any inflammatory condition, it must be remembered that the accompanying vascular dilatation tends to increase fluid exudation, and hence heat may be contra-indicated in such conditions where exudation may interfere with blood flow. It is *not unlikely* that one of the most important therapeutic effects of heat may be due to an increased rate of blood flow. Hence, mild applications of beat may bring about this desirable change, while intensive applications may produce capillary stasis with considerable fluid exudation and venous congestion

VI. Summary of Sources in Common Use. The discussion of the radiation characteristics of various types of radiators, and the relative penetration of thermogenic radiation into various media, including tissue, was for the purpose of clarifying certain misconceptions long held with respect to the matter The theoretical and experimental data presented show conclusively that the incandescent filament lamp heats the subcutaneous tissues, whereas the relatively low temperature infrared radiator heats chiefly the skin.

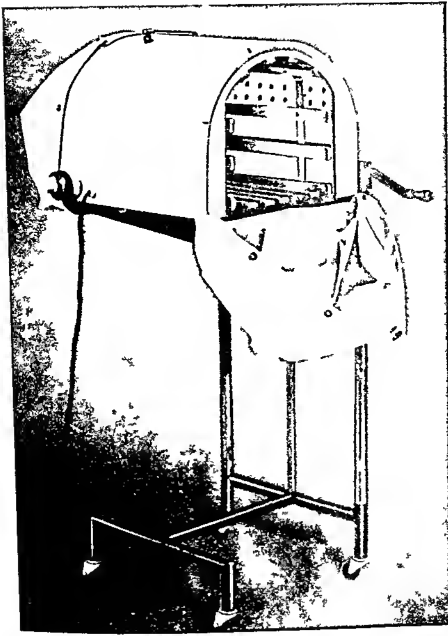


FIG 73a. Infrared baker for extremities adjustable for height and provided with thermostat control An example of a true non luminous radiator

FIG 73b Illustrating application to an extremity

The sources of thermogenic radiation in common use are tungsten filament lamps of various wattages, and electrical resistors mounted in suitable reflectors designed to prevent concentration of intensity, or so called "hot spots" In Table 22 are tabulated sources in current use, their salient characteristics and their field of usefulness

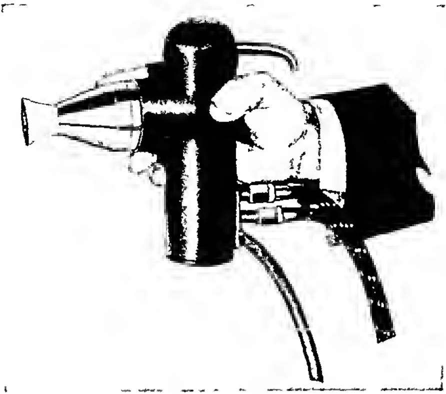


FIG 74 Source of luminous radiation for trans-illumination and thermal effects. Unit utilizes a tungsten filament lamp, is water cooled, and is equipped with a water filter (Cutler Lamp).

VII. TECHNIC OF APPLICATION

A. *Selection of Source.* If irradiation with themogenic radiation is an indicated therapeutic procedure, its use should be prescribed according to whether it is desirable to secure superficial heating or heating of the deeper layers of the superficial tissues. If superficial heating alone is desired, then a source of far infrared radiation should be prescribed. On the other hand, if heat in the deeper layers of the superficial tissues is desired, then a source of near infrared should be prescribed.

In those infectious cases requiring continuous hot moist dressings a thermostatically controlled generator of the non-luminous type, called a "baker," is placed over the area under treatment

TABLE 22

SUMMARY OF SOURCES OF THERMOGENIC RADIATION

Type of Radiation	Penetration	Field of Usefulness	Sources in Common Use
Far Infrared (15,000 to 150,000 A U)	1 mm to 05 mm *	For superficial heating	Electrically heated resistance wire, carborundum, or metallic plate—usually operated at temperature of 1000° K to 2000° K. a Mounted in suitable reflector and supported by adjustable floor stand—the so-called Infrared Lamp Fig 72 b Mounted in various shaped reflectors to facilitate irradiation of torso or extremities—the so-called "Baker" Fig 73.
Near Infrared (8000 to 15 000 A U)	10 mm to 1 mm *	For relatively deep heating	Incandescent lamp of various wattages ranging from 60 to 1000 watts a Mounted individually in reflector and supported by adjustable floor stand 1 With water filter Fig 74 2 Without water filter Fig 75 b Mounted in units of four or more in various shaped reflectors to facilitate irradiation of extremities or torso, the so-called "Baker" Figs 76 and 77

* Council on Physical Therapy, A M A *Apparatus Accepted* 1942

and covered with a blanket to prevent air circulation, thereby maintaining the requisite air temperature and humidity In this manner the rapid drying-out of the dressing is prevented, and its temperature maintained. The luminous type of generator can be used in the same manner, but without the advantage of assured maintenance of the air temperature at a desired level, since the use of thermostatic control is not readily adapted to this type of generator.

The advantages of this technic are the maintenance of the desired temperature and the ease with which the dressings are

kept in a heated, moist condition by applying, as necessary, appropriate, warm solution to the dressings without requiring their removal *The thermostatically controlled generator is particularly*

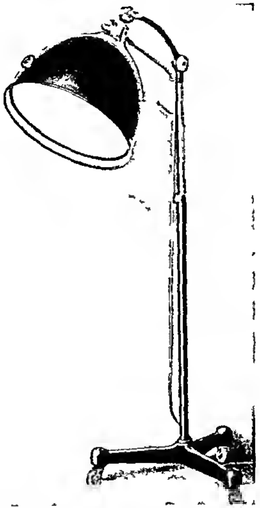


FIG. 75 Source of thermogenic radiation, equipped with high wattage tungsten filament lamp, emitting dominantly near infrared radiation

useful for the treatment of those conditions requiring prolonged treatment

B. *Caution* Krusen states. "A special warning must be issued not to apply the beat at too high temperatures in cases of vascular

disease Because of the impaired circulation, the heat may be dis seminated slowly and with difficulty Hence burns are more likely to occur and if burns do occur in these poorly vascularized tissues, disastrous consequences may result Severe sloughs and even gan

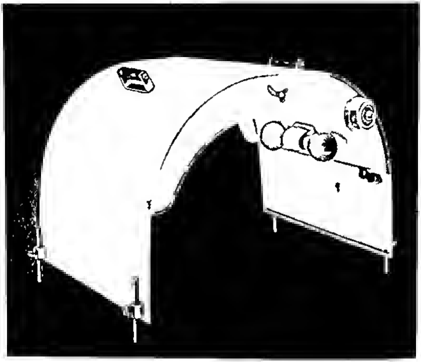


FIG 76 Baker equipped with incandescent lamps adjustable for height and width.

grene may occur *For this reason it should be remembered that in vascular diseases the temperature should not be greater than 105° F (40 6° C)* * It has been reported that temperatures of 30° C (86° F), in cases of circulatory disease, caused varying degrees of cyanosis and the patients complained of pain When the tem was increased to levels between 32° and 35° C (91 4° 95° F), pain diminished or disappeared and the color of the feet most closely approached the normal Cyanosis reappeared

* Authors Note This and the subsequent temperatures are those of the skin

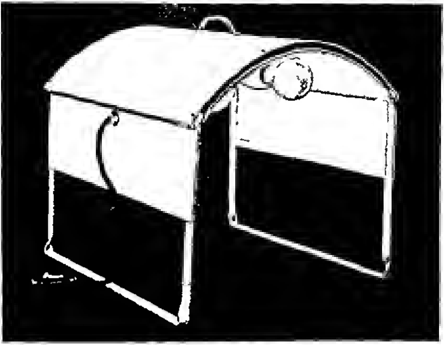


FIG 77 Small, portable baker of the incandescent lamp type

and pain returned when the temperature was greater than 35° C (95° F.) A temperature between 30° and 35° C. (86° and 95° F.) was employed, this temperature being maintained around the feet day and night by means of a thermo regulated foot cradle. Under such conditions some patients preferred temperatures differing slightly from those which they chose in the original experiments. It was finally decided that temperatures between 32° and 37.5° C. (89 6° and 99° F) were most satisfactory if prolonged treatment for circulatory diseases of the extremities was contemplated."[13]

C. *Details of Application*

1. The patient should be placed in a relaxed and comfortable position, the part to be treated exposed, and the rest of the body appropriately draped

[13] Krusen, Frank H Physical Medicine W B Saunders Company, Philadelphia. 1941, p 294

2 It should be definitely ascertained that there are no lesions of the sensory nerves to impair sensation

3 If sensation is subnormal, the technician should not administer thermogenic radiation to such area without specific instructions from the physician If infrared radiation is employed, it must be given with the utmost caution, or a trophic ulcer may develop with serious sequellae

4 The distance between the source and the skin of the part to be irradiated should be such that the intensity of the radiation will be well within tolerance The sensation of heat should be comfortable, and without localized "hot spots" over the area exposed Some drape a towel or other suitable material around the base of the reflector and reaching to the patient Fig 63, page 195 In this way the evaporation of perspiration from the skin surface is less with less cooling of the surface by evaporation and by air currents

5 Time of exposure is usually 20 to 30 minutes When perspiration begins to decrease, irradiation should be discontinued regardless of the time of exposure After a large number of treatments, the skin frequently will show a mottled pigmentation

D *Prescription*

Type of Radiation—Near or far infrared
Intensity—Wattage of generator
Source skin distance—Skin tolerance
Time—15 30 minutes
Frequency of Treatment—Daily
Area to Irradiate—Specify e g , Sacro iliac region

EXPERIMENT

Penetration of Near and Far Infrared Radiation Into Water

Object:

To determine the relative penetrating power of near and far infrared radiation into water.

Theory:

The penetration of thermogenic radiation into water, tissue, and other substances has heen discussed in the foregoing paragraphs Data were presented which showed that water is opaque to infrared rays longer than 14,000 A U. Data also were presented showing that the range of wavelengths penetrating most readily into tissue lie in the spectral band 5000 to 15,000 A U. witb maximum penetration at the wavelength of approximately 12,000 A.U. It was shown experimentally and hy computation that a higher percentage of the incident thermogenic radiation penetrated to a given depth of tissue if such radiation were first filtered by a water cell, such a cell ahsorbing the long infrared rays having negligihle penetration. To use terms from the nomenclature of x-ray therapy, the water filter "bardened" the radiation, ohtaining thereby a greater ratio of "depth dose" to "skin dose"

In this experiment the relative penetrating power into water of the radiation from an incandescent tungsten filament lamp, a source emitting dominantly near infrared rays (8000 to 15,000 A U. in wavelengtb), and of that from a resistance element, which emits dominantly far infrared rays (15,000 to 150,000 A U. in wavelength), will be determined. The intensity of radiation from these sources will be measured by means of a blackened bulb thermometer: first, the incident intensity of the beam; and then, the intensity of the beam after transmission through a water cell. The rate of rise of temperature as indicated by the thermometer will be proportional to the intensity of the radiation impinging upon and being absorbed by the blackened bulb after correction has been made for temperature loss due to cooling of the thermometer by radiation and convection. The method of making such correction will be explained under *Observations and Computations*

Apparatus:

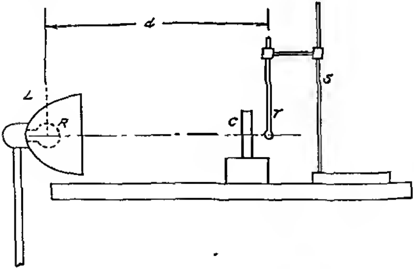
1. Thermogenic lamp with inter-changeable units: an incandescent filament lamp (250 watt, 110 volt, CX Mazda), and an infrared radiator (650 watt, 110 volt, wire wound). These were the sources used by the authors. Similar sources but of different wattages may be employed

2. Water cell, consisting of a vessel with plane, parallel glass sides, each about 3 mm. thick, spaced about 2 cm. apart, which is filled with water. Such a cell can be constructed by cementing with sealing wax two thin, 4 by 4 inch glass plates to 2 cm. thick wood spacers so arranged that a water-tight vessel open at the top is obtained

3. Thermometer with blackened bulb; blackening of bulb can be achieved by dipping bulb in thin mucilage and then in lampblack

4. A stop watch—if not available, ordinary watch with second hand can be used.

Procedure:



Arrangement of Apparatus for Experiment

The apparatus is arranged on a table as indicated in the illustration. L is the lamp; R, the source of radiation; T, a blackened bulb thermometer, supported by S, an appropriate stand; and C, the water cell. The distance *d* is 15 to 25 inches, depending upon intensity of radiation.

I. Incandescent filament lamp as source of radiation. (Dominantly near infrared)

A. No filter. Starting with the thermometer at room temperature, observe rise in temperature every ½ minute until temperature becomes stationary, or until the thermometer has risen 10 to 12 degrees C. After the source has been removed, continue observing the temperature every ½ minute until the thermometer again reads room temperature. Record temperature readings in a table like that appearing under *Observations and Computations*. Plot temperature against time, both during rise and during cooling period. From these curves correct temperature readings for loss by radiation and convection as was done for test recorded under *Observations and Computations*, and compute rate of rise of thermometer.

B. With Glass Filter. Place empty water-cell about 1 inch in front of thermometer and repeat test described in A, keeping distance between incandescent lamp and thermometer the same as in A. Record values in table, plot temperature against time, and make corrections for cooling as in A.

C. With glass filter plus water filter. Fill water-cell with water and repeat test B.

II. Infrared element as source of radiation (Dominantly far infrared).

A. No Filter. Procedure same as I-A

B. With Glass Filter. Procedure same as I-B

C. With glass filter plus water filter. Procedure same as I-C

Observations and Computations

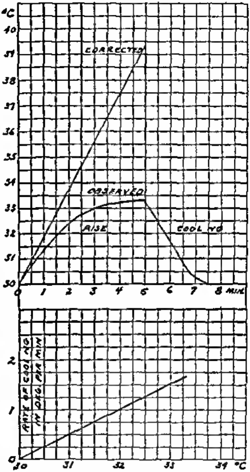
I. Incandescent lamp as source of radiation
Wattage, 250, Voltage, 110, Type, CX Mazda
Distance between lamp and thermometer 17 inches
A No filter
B 6 mm glass
C 6 mm glass+14 mm water

Min	Observed Temp			Corrected Temp *			Corrected Rise			Rise per Min		
	A	B	C	A	B	C	A	B	C	A	B	C
0	30 0°C	30 0°C	30 0°C	30 0°C	30 0°C	30 0°C	0°C	0°C	0°C	—	—	—
0 5	30 8	30 6	30 3	30 9	30 68	30 34	0 9	0 68	0 34	1 8	1 360	0 68
1 0	31 4	31 2	30 6	31 8	31 49	30 74	1 8	1 49	0 74	1 8	1 490	0 74
1 5	31 9	31 6	30 9	32 7	32 22	31 22	2 7	2 22	1 22	1 8	1 447	0 81
2 0	32 4	32 0	31 0	33 75	33 04	31 53	3 75	3 04	1 53	1 88	1 520	0 77
2 5	32 7	32 2	31 0	34 7	33 74	31 76	4 70	3 74	1 76	1 88	1 498	0 704
3 0	33 0	32 3	31 1	35 75	34 39	32 11	5 75	4 39	2 11	1 92	1 495	0 703
3 5	33 1	32 4	31 1	36 6	35 08	32 37	6 60	5 08	2 37	1 88	1 451	0 68
4 0	33 2	32 5	31 2	37 5	35 78	32 73	7 5	5 78	2 73	1 88	1 445	0 6825
4 5	33 3	32 6	31 2	38 4	36 5	33 01	8 4	6 5	3 01	1 87	1 444	0 67
5 0	33 3	32 7	31 3	39 3	37 26	33 40	9 3	7 26	3 40	1 86	1 452	0 68
5 5	32 6	32 0	31 0	—	—	—	—	—	—	—	—	—
6 0	31 7	31 2	30 7	—	—	—	—	—	—	—	—	—
6 5	30 8	30 9	30 4	—	—	—	—	—	—	—	—	—
7 0	30 2	30 6	30 1	—	—	—	—	—	—	—	—	—
7 5	30 0	30 3	30 0	—	—	—	—	—	—	—	—	—
8 0	—	30 0	—	—	—	—	—	—	—	—	—	—

Average rise per minute A, 1 86, B ,1 46, C, 0 71
Per cent of incident radiation penetrating glass filter
B−A×100%=1 46−1 75×100%=78 5%
Per cent of incident radiation penetrating glass filter plus water filter
C÷A×100%=0 71÷1 86×100%=38 2%

* *See facing page for footnote*

* The method employed in correcting for radiation and convection losses will be understood from the following description. In the accompanying chart the observed readings of the thermometer are plotted against time both during the time radiation was absorbed and during the cooling period. If no loss of heat from the thermometer had occurred the rise in temperature would have been directly proportional to the time and the resulting graph would have been therefore a straight line. However there was a marked decrease in the rate of rise. At the end of 5 minutes the temperature reading had become practically constant indicating that at this point the rate of loss of heat had become practically equal to the rate of absorption of heat. In order to determine what the temperature at the end of 5 minutes would have been had no decrease in temperature taken place due to loss of heat by radiation and convection correction must be made for such loss. This is done as follows.



Let us compute what the rate of decrease in temperature is when the thermometer has reached its highest reading. The decrease in temperature for the first minute during the cooling period is seen to be practically linear the temperature decreasing from 33.3° C to 31.65° C. The rate of decrease is therefore 1.65 degrees per minute. Let us now plot this maximum rate of cooling namely 1.65 degrees per minute at 33.3° C on a chart with rate of cooling as the ordinate and temperature as the abscissa. For temperatures that are but a few degrees above surrounding surfaces and absorbing media Newton's Law of cooling applies. This law states that the rate of heat loss is proportional to the difference in temperature between the hot body and its surroundings. Hence the graph of rate of cooling and temperature if surrounding temperature remains constant is a straight line. We already have one point on this straight line namely the point of maximum cooling. When the temperature of the thermometer is at room temperature the rate of radiation from it is zero. Thus we obtained a second point having the ordinate 0 and the abscissa 30° C. These two points determine the straight line from which the rate of cooling at any temperature of the thermometer can be readily determined.

Let us divide the heating curve into segments that are practically straight lines. The segments corresponding to ½ minute intervals are approximately linear. The average temperature during the interval 0 to 0.5 minute is 30.4° C. From the chart giving the rate of cooling at different temperatures the rate of cooling at 30.4° C is 0.2 de-

(Footnote continued on page 233)

II Infrared element as source of radiation
Wattage, 650, Voltage, 110, Type, wire wound
Distance between element and thermometer, 10 inches
A —No filter
B —6 mm glass
C —6 mm glass+14 mm water

Min	Observed Temp			Corrected Temp			Corrected Rise			Rise Per Min		
	A	B	C	A	B	C	A	B	C	A	B	C*
0	30 0°C	30 0°C	30 0°C	30 0°C	30 0°C	30 0°C	0	0	0	—	—	—
5	34 5	31 0	30 1	34 95	31 1	30 11	4 95	1 1	0 11	9 90	2 2	0 22
1 0	39 0	32 0	30 2	40 75	32 4	30 23	10 75	2 4	0 23	10 75	2 4	0 23
1 5	37 0	32 6	30 5	—	33 55	30 57	—	3 55	0 57	—	2 37	0 38
2 0	35 5	33 0	30 7	—	34 5	30 84	—	4 5	0 84	—	2 25	0 42
2 5	34 0	33 4	30 9	—	35 52	31 14	—	5 5	1 14	—	2 2	0 46
3 0	32 8	33 8	31 0	—	36 62	31 35	—	6 6	1 35	—	2 20	0 45
3 5	31 9	34 2	31 1	—	37 79	31 58	—	7 8	1 58	—	2 23	0 45
4 0	31 1	34 5	31 3	—	38 94	31 92	—	8 9	1 92	—	2 23	0 48
4 5	30 5	34 8	31 5	—	40 14	32 28	—	10 1	2 28	—	2 24	0 51
5 0	30 2	34 9	31 7	—	41 17	32 67	—	11 2	2 67	—	2 24	0 534
5 5	30 0	34 0	31 5	—	—	—	—	—	—	—	—	—
6 0	—	33 0	31 3	—	—	—	—	—	—	—	—	—
6 5	—	32 3	31 1	—	—	—	—	—	—	—	—	—
7 0	—	31 8	31 0	—	—	—	—	—	—	—	—	—
7 5	—	31 4	30 9	—	—	—	—	—	—	—	—	—
8 0	—	31 1	30 8	—	—	—	—	—	—	—	—	—
8 5	—	30 8	30 7	—	—	—	—	—	—	—	—	—
9 0	—	30 5	30 6	—	—	—	—	—	—	—	—	—
9 5	—	30 2	30 5	—	—	—	—	—	—	—	—	—
10 0	—	30 0	30 4	—	—	—	—	—	—	—	—	—
10 5	—	—	30 3	—	—	—	—	—	—	—	—	—
11 0	—	—	30 2	—	—	—	—	—	—	—	—	—
11 5	—	—	30 1	—	—	—	—	—	—	—	—	—
12 0	—	—	30 0	—	—	—	—	—	—	—	—	—

Average rise per minute A 10 33, B 2 26 C, 0 225
Per cent of incident radiation penetrating glass filter
B ÷ A × 100% = 2 26 ÷ 10 33 × 100% = 21 9%
Per cent of incident radiation penetrating glass filter plus water filter
C ÷ A × 100% = 0 225 ÷ 10 33 × 100% = 2 2%

* *See facing page for footnote*

Conclusions:

From the data obtained in the foregoing experiment it is evident that a much higher percentage of the incident radiation from a tungsten filament lamp penetrates to a given depth in water than does that from an infrared unit. In Table 23 is given the relative intensity of radiation from these sources without filter

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* Water has a high absorption for infrared radiation of wavelength greater than 14000 A.U Therefore, after a minute or two the temperature of the water-cell rises sufficiently high to act as a secondary radiator of extremely long wavelength radiation This secondary radiation is absorbed by the thermometer, resulting in an accelerated rate of temperature rise This accelerated rate of rise cannot, obviously, be taken as indicative of the intensity of the transmitted radiation The rate of rise during the first minute before the water-cell has begun to radiate, will be proportional to the intensity of the transmitted radiation The average rate of rise during this period is 225 degree per minute This was taken as proportional to the intensity of the transmitted beam

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(Footnote continued from page 231)

gree per minute During the interval 0 to 0 5 minute, the loss in temperature is 0 2×0.5 or 0 1 degree. Adding this loss in temperature to the observed temperature at 0 5 minute (30 8° C), we obtain the corrected temperature, 30 9° C The average temperature during the second interval, 0.5 to 1 0 minute, is 31 1° C The rate of cooling corresponding to this temperature is 0.55 degree per minute The loss in temperature during the second interval is therefore 0.55×0 5 or 0 275 degree. However, a loss of 0 1 degree occurred during the first interval Therefore, the total loss in temperature at the end of 1 minute equals the summation of losses during the preceding two periods, or 0 1+0 275 equals 375 degree This added to the observed temperature at the end of 1 minute (31 4° C) gives the corrected temperature at this instant, which is 31 4+ 375 or 31 775 or 31 8° C Proceeding in this way, the corrected temperatures are obtained These temperatures are plotted and the resulting graph is a straight line The slope of this line gives the increase in temperature per unit time and is proportional to the intensity of the radiation

To facilitate computation of corrected temperature a table such as the following will be found useful

Time Interval	Av Temp	Av Cooling Rate in Deg per Min	Temp Loss	Total Temp Loss
0–0 5 min	30 4° C	0 20	0 10°	0 10
0 5–1 0	31 1	0 55	0 28	0 38
1 0–1 5	31 7	0 85	0 43	0 81
1 5–2 0	32 2	1 10	0 55	1 36
2 0–2 5	32 6	1 30	0 65	2 01
2 5–3 0	32 85	1 47	0 74	2 75
3 0–3 5	33 05	1 52	0 76	3 51
3 5–4 0	33 20	1 60	0 80	4 31
4 0–4 5	33 25	1 62	0 81	5 12
4 5–5 0	33 30	1 65	0 83	5 95

and after transmission through 6 mm of glass and through 6 mm of glass plus 14 mm of water To obtain the same intensity of radiation after passing through the glass and water filter the incident intensity of the radiation from the infrared unit would have to be 38 2 — 2 2 or 17 4 times that of the radiation from the tungsten filament lamp

TABLE 23

Source	Relative Intensity		
	No Filter	6 mm Glass	6 mm Glass + 14 mm water
Incandescent Lamp	100%	78 5%	38 2%
Infrared Unit	100%	21 9%	2 2%

PART C RADIATION

SECTION THREE ULTRAVIOLET RADIATION

I DEFINITION Broadly speaking, ultraviolet radiation is that part of the electromagnetic spectrum which extends beyond the visible zone, commencing at about 4000 A U The spectral range of ultraviolet of interest to those employing it for therapeutic purposes extends from about 3200 A U to the limit of transmission of quartz, about 2000 A U

II GENERATION

A *Natural Source* The great source of all radiation is the sun In Fig 78 is shown the spectral distribution curve of solar radiation You will note that solar radiation, after filtration by the atmosphere, provides practically no radiation of wavelengths shorter than 2900 A U In urban communities, located in the temperate zone, and having much soot and other impurities in the atmosphere, the biologically significant component of ultraviolet radiation, spectral range 2000 A U to 3200 A U, is negligible throughout the greater part of the year Only at high altitudes, and at lower altitudes during the summer in the temperate zones, does sunlight contain an adequate component of ultraviolet radiation for therapeutic purposes Another disadvantage is the high component of heat producing radiation present in summer sunlight, which may be contraindicated in certain conditions It is obvious that reliance must be based on artificial sources throughout the greater part of the world Artificial sources can be used at any time, and will always deliver the same type and intensity of radiation, making possible duplication of technic

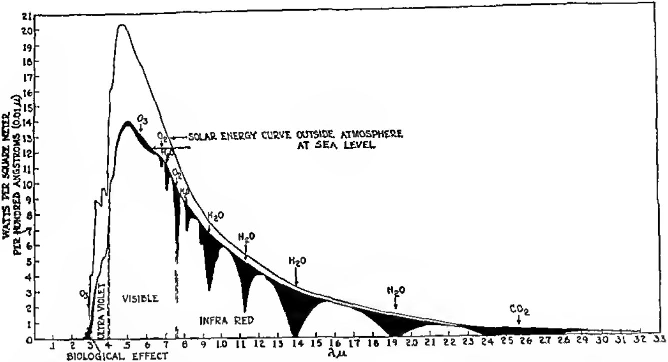


FIG 78 *Curves showing the distribution of energy in the solar spectrum* outside the atmosphere and at sea level The intensities in the latter curve are read from the lower edges of the darkened areas which are due to selective absorption of the substances in our atmosphere which are indicated above the curve (From Pettit Edison The Sources of Ultraviolet Light Western Hospital and Nurses Review 12 5 January 1929 Corrected by Petit on basis of later measurements reported in Mount Wilson Contributions No 445 and No 622 published in the Astrophysical Journal Vol 75 1932 and Vol 91 1940

Furthermore, such sources can be designed to deliver a high intensity of ultraviolet of the desired wavelengths without delivering an excessive quantity of thermogenic radiation. We shall, therefore, confine this discussion to the use of artificial sources.

B. *Artificial Sources* Artificial sources of ultraviolet radiation fall into three classifications: hot body radiators; electric arcs; and glow discharges. There are many specific devices on the market, but all of them fall into one or another of the foregoing classifications. Hence we shall discuss artificial sources from the viewpont of this classification, dealing under each classification with representative devices, for it is obvious that a survey of all generators available today is impossible. For information on specific devices, the booklet *Apparatus Accepted,* published by the Council on Physical Therapy of the American Medical Association, should be consulted.

1. *Hot Body Radiators.* Hot body radiators such as tungsten filaments operated at high temperature within bulbs of ultraviolet transmitting glass, such as Corex, have been used as sources of ultraviolet radiation. A consideration of Fig. 67, page 202, will convince one of the fact that a tungsten filament operated at 3000° K will emit but a very small per cent of its total radiation output at wavelengths shorter than 3200 A.U., the upper limit of the ultraviolet spectral zone having established biologic effects. The vast majority of its emission consists of visible and infrared radiations. A hot body radiator such as the CX lamp, according to measurements given in Table 25, page 251, emits radiant energy of wavelengths less than 3135 A U. The intensity, however, of the radiation in microwatts per square centimeter at a distance of 30 inches from the lamp is only 1.2, whereas that of the sun is 91: a ratio of 91 to 1.2, or about 76, in favor of the sun. An exposure of 10 minutes to summer sunlight would provide a total amount of ultraviolet energy equivalent to that received in 760 minutes, or 12 hours and 40 minutes, at a distance of 30 inches from a CX lamp It is evident that hot body radiators are impractical as sources of ultraviolet for therapeutic purposes

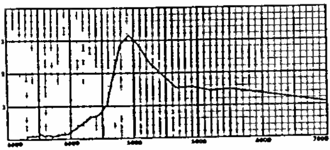
2. *Electric Arcs.* The practical sources of therapeutic ultra-

violet radiation are limited to electric arcs between electrodes of metal of carbon or of carbon impregnated or cored with various metals, and to electric arcs maintained in mercury vapor within tubes of fused quartz, a material which is highly pervious to ultra violet radiation Glow discharges within fused quartz tubes, con taining mercury vapor at low pressure have also been employed for the generation of ultraviolet radiation Low pressure mercury glow lamps emit about 95 per cent of their total ultraviolet out put at the wavelength of 2537 A U Its field of usefulness is extremely limited

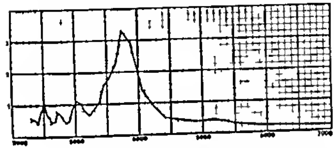
a *Carbon Arc* When two electrodes of electrically conductive material, to which an electric potential is applied, are brought into contact and then separated, an electric arc is established The radiation from such arcs consists of a number of fine lines so close together that the spectrum appears continuous when viewed by a small spectroscope Superimposed on the radiation from the arc vapors is the continuous spectrum from the highly incan descent crater of the positive electrode The result is an intense infrared spectrum of wavelengths longer than the solar rays which are transmitted by the atmosphere If the arc is surrounded with a glass or quartz globe, some of the infrared rays are excluded, but in turn the surrounding globe becomes heated, and emits infrared rays of long wavelength Hence, no exact comparison can be made between the radiation from the sun and that from the carbon arc

The range of wavelengths emitted by an electric arc depends on the elements present in the electrodes Each element emits its characteristic spectrum The electrodes usually employed are of solid carbon, or of carbon impregnated or cored with various metals By judicious choice of various metals, the intensity of the radiant energy delivered in different spectral regions may be enhanced Spectral emission, so far as wavelength is concerned is primarily determined therefore, by the composition of the elec trodes The quantitative radiation output from an electric arc between electrodes of given composition is determined by the power dissipated in the arc To summarize, then, the quantity of radiation delivered in the infrared, the visible, and the ultra violet zones by a carbon arc lamp depends upon the following

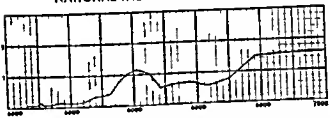
NATIONAL SUNSHINE CARBON



NATIONAL THERAPEUTIC C CARBON



NATIONAL THERAPEUTIC E CARBON



WAVE LENGTH IN ANGSTROM UNITS

FIG 79 Radiation characteristics of representative therapeutic carbons (Courtesy of the National Carbon Company)

(1) The size and composition of the electrodes used,
(2) The electrical power consumed in the arc, and
(3) The efficiency of the reflector with which the arc is equipped

The effect of the composition of electrodes on the spectral distribution of the emitted radiation is shown in Fig 79 The spectral distribution curves are of arcs between carbon electrodes known as 'Sunshine Carbon," "Therapeutic C Carbon," and "Therapeutic E Carbon" The *Sunshine Carbon* contains cerium and

sion from these electrodes on being heated, ionizes the gases within the tube, permitting automatic starting In the second type a third, or starting electrode of pure tungsten—as are the two main electrodes—is sealed into one end of the tube in addition to the main electrode The full voltage of the secondary of the trans former is applied across the starting electrode and the regular electrode which are spaced close together at the same end of the

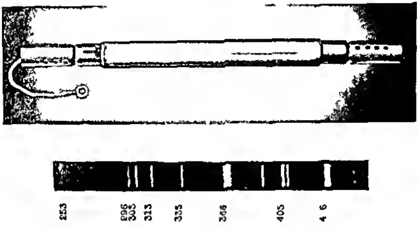


Fig 80 New type hot quartz mercury vapor arc burner and spectrogram of its ultraviolet emission

tube The arc starts between these electrodes and then extends to the regular electrode at the other end of the tube after the gas has been ionized After the mercury arc has been established be tween the main electrodes, a thermo relay opens the circuit to the starting electrode After the lamp has been turned off about 5 minutes cooling time must be allowed before re striking the arc Otherwise the arc will not be reestablished The fact that the electrodes are of pure tungsten and uncoated would seem to indicate a relatively long life for no flaking off of oxide would take place

In Fig 80 is shown the new type of burner and the spectrogram of the ultraviolet radiation emitted by it In Table 24 are given comparative radiation data on an alternating current burner with

emission type electrodes and an older liquid mercury cathode type The output of radiation in the spectral zone 2483 A U to 3129 A U, in microwatts per square centimeter at one meter from the burner, is 276 2 in the case of the new type lamp, and 207 46 in the case of the older type an increase in output of biologically significant radiation of about 33 per cent

The arc wattage of the new type burner, however, was 360 while that of the liquid mercury cathode type was 281 Therefore, the output of biologically significant radiation, $\lambda = 2483$ A U

TABLE 24

RADIATION DATA ON TWO TYPES OF HOT QUARTZ MERCURY ARCS (Without Reflectors)

	Old Type Liquid Hg Cathode D C Uviarc 120 V Line*	New Type Oxide-coated Electrodes A C Uviarc (360 W) 110-120 V Line**
Arc volts	75	136
Arc amperes	3 75	2 9
Arc watts	281 0	360
Total watts	450 0	410
Wavelength of Principal Line	Micro Watts per Sq Cm at One Meter	
4047 A U	34 1	45
3654	103 0	122 0
3341	7 7	11 6
3129	71 0	85 0
3022	31 4	39 4
2967	15 6	20 9
2894	5 7	8 3
2804	10 9	15 7
2753	3 46	5 5
2 00	4 6	7 6
2652	23 4	33 1
2537	32 0	47 4
2483	9 4	13 3
3129 to 2483 Incl	207 46	276 2

* Data courtesy of L J Buttolph Nela Park Engineering Dept. General Electric Company

** L B Johnson and S B Webster Rev Sci Instruments Oct 1938

to $\lambda = 3129$ A U, per watt input into the arc is 0 767 microwatts per square centimeter at one meter for the burner with oxide coated electrodes and 0 740 microwatts per square centimeter for the liquid mecury cathode type of burner The increase in output of therapeutically useful radiation per watt input is therefore about 3 7 per cent The older type lamp could have been operated at a higher arc wattage and a higher total radiation output obtained The chief advantages of the new type of burner are those which were presented in a foregoing paragraph and not a possible increase in output per watt input of the order of 5 per cent or less

The curve in Fig 81 gives the experimentally determined time for a mild erythema on average untanned skin at various distances from a hot quartz mercury vapor arc type of lamp, with the new type A C burner and properly designed reflector The time for an erythema for different patients varies greatly, but the curve in Fig 81 will give an idea of the relative increase in time required as distance is increased At 30 inches the time determined in this test was approximately 0 5 minute and at 40 inches 1 0 minute Although distance is increased only 33⅓ per cent, the exposure time is increased 100 per cent *

* Let us compute what the exposure should be on the basis of the inverse square law

Let I_1 = intensity at 30 inches and

I_2 = intensity at 40 inches

Then applying the inverse square law

$$\frac{I_2}{I_1} = \frac{30 \times 30}{40 \times 40} = \frac{9}{16} \text{ or } \frac{I_1}{I_2} = \frac{16}{9}$$

Now let t_1 = number of minutes for a mild erythema at 30 inches and

t_2 = number of minutes for an equal erythema at 40 inches

Then $I_1 t_1$ = total energy received at 30 inches and

$I_2 t_2$ = total energy received at 40 inches

Since the same effects are to be obtained

$$I_2 t_2 = I_1 t_1 \text{ and}$$

$$t_2 = \frac{I_1}{I_2} t_1 = \frac{16}{9} t_1 \text{ substituting the value of the ratio } \frac{I_1}{I_2}$$

If $t_1 = 0\ 5$ $t_2 = \frac{16}{9} \times 0\ 5$ or about 0 9 minute

This computed value agrees sufficiently well with the measured time value

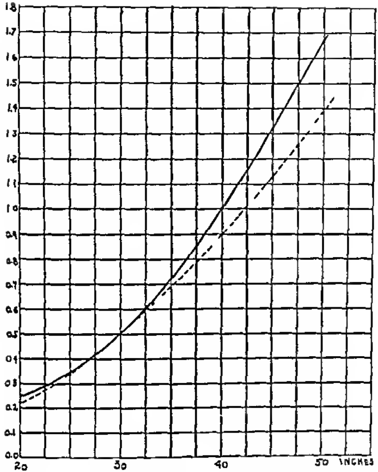


Fig 81 Time for mild erythema on average untanned skin at various distances from an ultraviolet lamp with new type A C burner and properly designed reflector Solid curve from actual measurement of time Dotted curve computed from *Inverse Square Law* taking time at 30 inches as 0 5 minute

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to justify the use of the inverse square law to estimate exposure times at various distances from this particular lamp It is suggested that the user of a lamp prepare a curve similar to that in Fig 81 for the lamp he uses in order that he might have a better realization of the approximate time for producing an erythema at various irradiation distances.

(2) *Mercury Arcs in Corex* Various types of mercury arcs within envelopes of an ultraviolet transmitting glass such as *Corex* have been produced for use as sun lamps The type of radiation emitted by such arcs before undergoing modification through filtration by the *Corex* envelope is that obtained from typical high pressure mercury arcs The *Corex* bulb does not transmit radiation shorter in wavelength than 2800 A U the output therefore will not contain wavelengths shorter than 2800 A U It is not possible because of limited space to discuss in detail the various lamps of this nature that are or have been available The discussion will be restricted to two representative types the *S lamps* of which there are two sizes the *S 1* and the *S 2* and the more recently developed sunlamp the *Mazda R S Sunlamp* Such lamps are principally for use in the home during the season when solar ultraviolet is not available These like the *Sunshine* carbon arc lamps are not designed for medical use

(a) *The S 1 and S 2 Lamps* The *S 1* lamp is shown in Fig 82 Essentially the lamp consists of a mercury arc operating between tungsten electrodes and in parallel with a tungsten filament When current is passed through the filament the filament is heated and mercury from the small pool under the filament is vaporized Soon an arc is established in the mercury vapor between the tungsten electrodes The enclosing bulb of *Corex* absorbs wavelengths shorter than 2800 A U The *S 2* lamp is similar but of lower output The average time for a mild erythema is 10 to 15 minutes for the *S 1* lamp at 30 inches and for the *S 2* lamp at 24 inches These lamps do not operate directly on the house current but require a special re

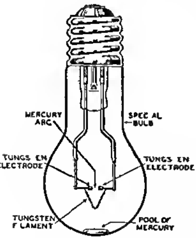

FIG 82 Mazda *Sunlight* lamp (Type S 1)

actance transformer. The unit is of necessity designed for operation on alternating current. The special transformer is usually housed in the base of an appropriately designed lamp fixture. These lamps are useful devices for home treatment but under medical supervision.

(b) *Mazda R-S Sunlamp* This lamp is a self-ballasting mercury vapor lamp with a built-in reflector. The lamp has two bulbs: the outer bulb of an ultraviolet transmitting glass which absorbs the shorter ultraviolet rays of wavelength less than 2800 A.U., and an inner bulb of quartz. The reflecting surface is deposited on the inside of the outer bulb—known as an *R-40* bulb. The ballast consists of a tungsten filament located between the two bulbs. The heating of this filament to incandescence provides thermogenic radiation, visible and invisible, which added to the ultraviolet radiation emitted by the mercury arc within the quartz bulb gives a total output ranging in wavelength through the infrared, the visible, and the ultraviolet to about 2800 A.U. The outer bulb is so shaped that when its upper portion is covered internally with a deposition of metal having appropriate reflecting characteristics, no other reflector is required with the lamp.

This lamp is designed to be operated on the ordinary lighting circuit of 110 to 120 volts, and requires about 275 watts. The time for a mild erythema is about 5 minutes at a distance of 24 inches. If we assume that the inverse square law holds sufficiently close for an estimate of exposure time for a similar erythema at other distances, the time for an erythema at 30 inches would be $\frac{30 \times 30}{24 \times 24} \times 5$ or 7.8 minutes. This lamp, provided its burning life is found to be sufficiently long to be economical, appears to be a convenient and sufficiently intense source of ultraviolet radiation for home use under medical supervision.

c. *Finsen-Lomholt Carbon Arc.* A special carbon arc lamp has been developed by the Finsen Institute of Copenhagen, specially designed for the treatment of lupus vulgaris. The lamp consists essentially of a carbon arc, using carbon electrodes of special composition, and various filters Cooling is provided by a jacket, through which water is circulated. Connection must be made to

the water supply system to assure adequate cooling A combination of three filters is used with the lamp These are

1 An anterior chamber of circulating water to absorb the heat producing radiation emitted by the arc while transmitting a large percentage of the ultraviolet radiation

2 A filter, several centimeters thick, of copper sulfate dissolved in concentrated ammonia which absorbs visible radiation of wavelength greater than 5000 A U while transmitting readily the ultraviolet rays

3 A filter of cobalt sulfate dissolved in a very weak solution of sulfuric acid, of sufficient thickness to absorb most of the radiation from 4000 A U to 5500 A U while permitting the passage of ultraviolet rays with but slight absorption

By means of this series of filters, it was found that seventy per cent of the transmitted radiant energy would be of wave lengths less than 4000 A U This filtration was obtained with an absorption of but 25 per cent of the radiant energy of wave lengths less than 4000 A U emitted by the arc

In conjunction with the filters, an optical system of fused quartz is employed, which concentrates the radiation to a small area about three quarters of an inch in diameter This lens also permits the application of regulated pressure during irradiation Such a lamp has been in operation in the Department of Physical Therapy at the Northwestern University Medical School for the past two years and has been found to be the most effective method for the treatment of lupus vulgaris especially of small areas

The lamp requires considerable power, the arc current being of the order of 35 amperes at a voltage of 55 volts Hence, a special power line of sufficient capacity must be provided It is not a mobile unit since permanent connection to a cold water supply is required

3 *Mercury Glow Discharge Lamp* Lamps of this type, the so-called *Cold Quartz* lamps, are essentially low vapor pressure, low amperage (0 015 amperes), high potential (5000 volts, open circuit), glow discharges within mercury vapor, contained within fused quartz tubes They are similar to the well known Geissler

tubes. The power consumption is small, hence there is no great rise in the temperature of the burner.

The burner is of transparent fused quartz tubing, highly evacuated, and containing rare gases such as xenon, krypton, argon, and neon, and a few drops of mercury. The purpose of the rare gases is to facilitate the glow discharge The tubing is wound into a flat, grid type of coil for general irradiation, or the tube may be straight for orificial or highly localized irradiation.

Of the total radiation of all wavelengths less than and including the line at 3130 A U, more than 95 per cent is contained in the resonance emission line of mercury at 2537 A.U.

The erythemogenic efficiency of this type of lamp is high, but practically all of the erythemal effect is produced by the radiation of wavelength 2537 A.U.

According to the Council on Physical Therapy of the American Medical Association, however, the fact that the erythemogenic efficiency of a source is high is not necessarily a criterion of its suitability for therapeutic purposes [1]

By providing suitable ionization by means of electrons emitted from a hot cathode, only a relatively low voltage is required to excite resonance radiation in the glow discharge through mercury vapor. The emission characteristics of such a lamp, so far as the output of biologically important ultraviolet radiation is concerned, is similar to the high voltage mercury glow lamp, which was discussed in the preceding paragraph

Glow discharge lamps of the foregoing types have been used for both therapeutic purposes and home use It is not established that such lamps are to be preferred to the widely used low voltage, hot quartz mercury arcs for medical purposes According to Coblentz, the question has arisen whether the type of ultraviolet radiation emitted by the so called "cold quartz" lamp should be used for general body irradiation, or whether its application should be confined to special conditions Under *Biologic*

[1] Council on Physical Therapy, A.M.A. Apparatus Accepted, p 72 A M A, Chicago, 1942

Effects the effects produced by radiation of the wavelength generated by this type of lamp will be discussed. It will be shown that such radiation has but a negligible penetration into tissue, and, therefore, although strongly bactericidal, such radiation can affect bacteria only on the surface. Even a thin film of oil would protect the bacteria from the radiation[2] Furthermore, such radiation will not bring about tanning of the skin The chief application of radiation of this nature is for the sterilization of air The sterilization of air can be effected under proper conditions, but it is absurd to rely upon such radiation to sterilize objects covered with films of organic matter.

C. *Discussion.* From the foregoing it must be concluded that the only practicable sources of ultraviolet radiation for medical use are the electric arcs They emit energy throughout the spectral zone of biologic importance, that is, of wavelengths shorter than about 3200 A U. These are the sources in common medical use The relative efficiency of various arcs as emitters of therapeutic ultraviolet radiation is shown in Table 25, adapted from that presented by Koller[3] From the data given by Koller the energy output of wavelengths shorter than 3135 A U. was computed for the various sources considered The number of microwatts per square centimeter per watt input delivered by the quartz mercury arc of wavelengths less than 3135 A U was taken as 100 per cent, and the relative efficiency of the other sources computed These computations appear in the last two lines of Table 25

The excessively high output of infrared and visible radiation in comparison with the ultraviolet output in the spectral zone of wave-lengths shorter than 3000 A U. in the case of the carbon arc lamp, is brought out in Table 26, based on data presented by Seitz[4] In this table, the output of ultraviolet radiation of wavelengths below 3000 A U. is considered 100 per cent in the case

[2] Koller, L R Bactericidal Effects of Ultraviolet Radiation Produced by Low Pressure Mercury Vapor Lamp Jour Applied Physics 10 9 624 (Sept) 1939

[3] Koller, L. R. Production, Transmission, and Reflection of Ultraviolet Radiation General Electric Review 39 5 232 (May) 1936

[4] Seitz, E A Ultraviolet Radiators and Their Biologic Evaluation Brit Jour Physical Medicine 11 10 (Feb) 1937

TABLE 25

ENERGY IN MICROWATTS PER CM² OF WAVELENGTHS SHORTER THAN 3135 A.U FALLING ON A SURFACE 30 IN FROM LAMP

	Quartz Mercury Arc (a)	S1 Unit (a)	S2 Unit (a)	CX Lamp (a)	Sun (e)	Carbon arcs (no reflector) (b)						
						Sun shine	C	E	K	U	Mirror Arc	High Intensity
Arc volts	75	12 2	11 4			50(ac)	50(ac)	50(ac)	50(ac)	50(ac)	55(dc)	56 5(dc)
Arc amperes	3 75	28 7	9 1			60	60	60	60	60	30	90
Arc watts	281	350	104	500		3000	3000	3000	3000	3000	1650	5085
Microwatts per cm²	400(c)	260(d)	55(d)	1 2	91	446	1280	232	553	1398	94	532
Microwatts per cm² per watt input	1 42	0 743	0 528	0 0024	—	0 149	0 427	0 077	0 184	0 466	0 057	0 104
Relative efficiency	100%	52 3%	37 2%	0 169%	—	10 5%	30%	5 4%	13%	32 8%	4 02%	7 3%

(a) "Ultraviolet Sources and Their Radiation," by W E Forsythe, B T Barnes and M A Easley, *Journal of the Optical Society of America*, vol 24, No 7, July 1934, pp 178–182

(b) From data supplied by Dr A C Downes, National Carbon Co, Cleveland, Ohio

(c) In direction perpendicular to axis of lamp No reflector

(d) Unit tilted 30 deg from vertical Radiation measured on axis of reflector

(e) Noonday June sun at Washington, D C

Sunshine Carbon Cores of the cerium group of rare earth elements

"C" Carbon Cores containing iron, aluminum and nickel

"E" Carbon Cores containing strontium

"K" Carbon Cores containing cobalt

"U" Carbon Cores containing chromium, manganese, iron, and titanium

Low intensity Carbon Neutral Core Cores containing nothing but potassium silicate

Direct-current High intensity Carbon Cores containing the cerium group of rare earth metals

TABLE 28

TRANSMISSION AND ABSORPTION OF RADIATION BY HUMAN SKIN (ACCORDING TO BACHEM AND REED)

Layer	Thickness in mm	Wavelength in Angstroms									
		Ultraviolet					Visible Light		Infrared		
		2000	2500	2800	3000	4000	5500	7500	10000	14000	
		100	100	100	100	100	100	100	100	100	Applied Intensity
Corneum	0 03	100	81	85	66	20	13	22	29	56	Absorbed and reflected
		0	19	15	34	80	87	78	71	44	Transmitted
Malpighu	0 05	0	8	6	18	23	10	13	6	16	Absorbed
		0	11	9	16	57	77	65	65	28	Transmitted
Corium	2 0	0	11	9	16	56	72	44	48	20	Absorbed
		0	0	0	0	1	5	21	17	8	Transmitted
Subcutaneous	25	0	0	0	0	1	5	20	17	8	Absorbed
		0	0	0	0	0	0	1	0	0	Transmitted

solely to the presence of dissolved substances, but may be due also to the presence of very small particles. Hulbert[7] found that in the range 2500 A.U. to 3000 A.U., the $MgCl_2$, the $CaSO_4$, and the water constituent of sea water each contribute about one-third to the absorption, the other salts that may be present contributing but little.

B. *By Tissues.* The penetration of ultraviolet radiation into tissue is not great in comparison with the penetration of thermogenic radiation. There is disagreement as to the exact penetration of different wavelengths. The most careful determination of the transmission of human skin for ultraviolet radiations seems to be that of Bachem and Reed.[8] In Table 28 their data on transmission of human skin for wavelengths from 2000 A.U. to 14,000 A.U. are given.

TABLE 29

STRUCTURE OF THE SKIN

1	Outer Skin (Epidermis)	Stratum Corneum (Horny Layer)
		Stratum Lucidum (Lucidum)
		Stratum Granulosum (Granulosum)
		Stratum Mucosum (Malpighian Layer)
Basement Membrane		
2	True Skin (Derma, Corium, or Cutis Vera)	Papillary Layer, Containing Nerve Endings and Capillaries
		Reticular Layer, Made up of Fibrous Bundles
3	Subcutaneous Connective Tissue	(Contains Lymphatics, Blood Vessels, Nerves, and Fat in Variable Degree)

[7] Hulbert, E. O.: The Penetration of Ultraviolet into Pure and Sea Water. J. Optic. Soc. America 17:1-15 (July) 1928.

[8] Bachem, A., and Reed, C. I.: The Penetration of Light Through Human Skin. Am. J. Physiology 97:1 86 (April) 1931.

The skin is made up of (1) an epithelial layer, called the *epidermis*, *cuticle*, or *scarf skin;* and (2) the true skin, called the *corium*, *derma*, or *cutis vera.* Each is composed of several layers, from without inward, as shown in Table 29. In Fig. 83 is shown a spatial diagram of the skin, taken from Lewis,[9] giving the structural layers and the arrangement of the arterial and venous plexuses at various levels.

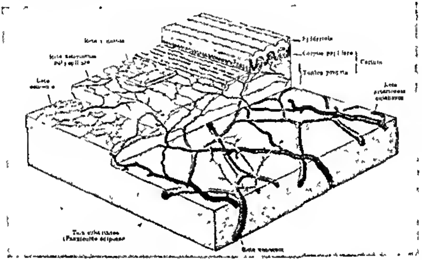

FIG. 83. Spatial diagram of the skin and its tissues. (From Lewis, Thomas. The Blood Vessels of the Human Skin and Their Responses. Shaw and Sons, Ltd, London, 1927.)

A study of this diagram, in conjunction with the transmission data presented in Table 28, will enable one to visualize the skin layers to which ultraviolet rays of various wavelengths will penetrate. The far ultraviolet from 2000 to 2800 A.U. has only a superficial penetration of from *0.1 to 0.5 mm.;* the near ultraviolet from 2800 A.U. to 3200 A.U. about *0.5 to 1 mm.* Ultraviolet radiation is absorbed by protoplasm, and this absorption results in physical and biologic changes which manifest themselves only several hours after exposure.

[9] Lewis, Thomas: The Blood Vessels of the Human Skin and Their Responses. Shaw and Sons, Ltd., London, 1927.

C *By Various Filters* Filters are not used as extensively as they might be in infrared and ultraviolet therapy Reference has been made, page 206, to the use of a water filter and a filter of heat transmitting glass in conjunction with a tungsten filament lamp to filter out the long infrared rays and the visible rays By their use, the emission from the tungsten lamp is confined chiefly to radiation in the spectral zone from 8000 A U to 15,000 A U, the range of thermogenic wavelengths which penetrate relatively deeply into tissue

By the use of appropriate filters, various zones in the ultraviolet region may be isolated The selection of a filter will depend upon the effect it is desired to produce, a filter or combination of filters is selected which will permit the passage of those radiations that are particularly effective in producing the desired effect

Most sources of ultraviolet radiation, particularly the carbon arc lamp, emit a heterogeneous band of radiation extending from the long infrared rays, through the visible, and into the ultraviolet The shortest wavelength in the ultraviolet to which the emission spectrum extends, varies widely depending upon the type of source employed, as was described in the discussion on sources of ultraviolet radiation Consequently, much confusion has existed as to the particular range of wavelengths which produce an observed *clinical effect* *Filters may be employed satisfactorily* to limit radiation from a source, and thereby provide the means whereby a more accurate evaluation of the clinical value of different spectral zones may be obtained

To limit the radiation from a source to a given spectral zone, more than one filter may be required, especially when the source emits a high intensity of visible and infrared radiation in addition to ultraviolet radiation A water cell will effectively absorb the long infrared radiation of wavelength greater than 15,000 A U A filter, transparent to the desired range of ultraviolet radiation but opaque to visible and near infrared rays, if used in conjunction with the water cell, will limit the transmitted radiation to the desired band of ultraviolet wavelengths If the intensity of the radiation absorbed by the ultraviolet transmitting filter is high, the water cell should be placed in contact with the filter, and

cool water circulated through the cell In this way, heat will be conducted away and the filter protected from excessive heating If the lamp is enclosed, a water jacket should be provided to protect the lamp from excessive heating

If the fluorescent effects of ultraviolet radiation are to be utilized rather than its biologic effects, appropriate filters must be employed The transmission characteristics of such filters will be discussed later

Most optical materials used for lenses and filters are opaque to ultraviolet rays of the spectral zone which has been found useful therapeutically In this discussion the transmission characteristics of representative materials will be considered The various optical materials concerning which information might be of most value, are ordinary window glass, Corex, and certain special filters which have selective transmission characteristics useful for the purpose of isolating various spectral zones

1 *Ordinary Window Glass* Ordinary window glass effectively absorbs ultraviolet radiations of wavelength less than 3100 A U, a thickness of 3 3 mm permitting only about 1 per cent of the incident radiation at 3100 A U to pass through At 3020 A U no energy is transmitted [10]

2 *Ultraviolet Transmitting Window Glass* In an endeavor to make available the biologically important component of natural sunlight, various substitutes for window glass, having relatively high transmission for solar ultraviolet in comparison with ordinary window glass, have been developed Such glass has been recommended for solaria installations

Extensive tests of such materials have been made by Coblentz [11] According to him, the better grades of this type of glass in thicknesses of 2 3 mm have an average transmission of the order of 60 per cent at the wavelength of 3020 A U when new After ex

[10] Coblentz W W Stair R Data on Ultraviolet Solar Radiation and the Solarization of Window Materials Research Paper No 113 Bureau of Standards J Research 3 629 (Nov) 1929

[11] Coblentz W W Stair R Data on Ultraviolet Solar Radiation and the Solarization of Window Materials Research Paper No 113 Bureau of Standards J Research 3 629 (Nov) 1929

posure to a quartz mercury arc at a distance of 15 cm. for a period of 10 hours, the transmission drops to about 40 per cent.

Under optimal conditions, the radiant energy delivered by the sun does not extend toward the shorter wavelengths much beyond 3000 A.U. When the biologically important component of sunlight is adequate for therapeutic use or for prophylactic purposes, the weather is such that open air helintherapy may safely be practiced, and at such times there would be no need for a solarium equipped with such glass In urban communities, particularly located in the temperate zones, the ultraviolet component of sunlight is negligible. It is stated by Krusen[12] that "in a room with ultraviolet transmitting glass windows and with a northern exposure [*authors' note:* northern skyshine has a high intensity of ultraviolet when a high intensity is present in sunlight] it would be necessary for an individual to remain for at least twenty hours in a portion of the room in which the illumination was equivalent to 10 foot candles in order to obtain the same amount of ultraviolet radiation as he would receive from two minutes of exposure to noon June sunlight." Krusen concludes that "during the short time an office worker or school boy would be out to lunch he would receive more ultraviolet radiation than could be obtained from an all day exposure through ultraviolet transmitting glass "

Obviously, the use of expensive ultraviolet transmitting glass for the glazing of office and schoolroom windows is not warranted Furthermore, the use of such material is unnecessary in solaria in view of the fact that high intensity sources of ultraviolet energy of the preferred range of wavelengths are available. In solaria equipped with such sources, irradiation may be administered at any time without regard to climatic conditions. With such high intensity sources, the desired erythemal dose can be administered in a short time of the order of 1 to 5 minutes, permitting the economic ultraviolet irradiation of large numbers in a comparatively short time.

3. *Corex.* The trade name of glasses for transmitting ultra-

[12] Krusen, F. H.: Physical Medicine. W. B. Saunders Co, Philadelphia, 1941

TABLE 30

Wavelength in A U	Transmission in Per Cent			
	Corex A CG980A Neutral 2 mm	Corex D CG970 Neutral 2 mm	U V Transmitting CG587 Red Purple 2 mm	Corex A CG986 Red Purple 3 mm
2200	1 15	0	—	—
2400	23 7	0 27	—	0
2600	53 1	3 9	—	13 5
2800	75 3	30 5	0	41 2
3000	84 0	70 0	3 9	62 5
3200	87 9	86 0	34 2	79 3
3400	88 4	90 2	64 0	81 4
3600	88 5	—	79 5	79 7
3800	—	—	70 0	43 0
4000	88 7	—	26 5	7 5
4200	—	—	4 5	2 3
4400	89 3	—	1 0	0
4600	—	—	1 0	0
4800	89 7	—	0 5	0
5000	—	—	0	0
5200	90 0	—	0 5	0
5400	—	—	0 5	0
5600	90 0	—	1 0	0
5800	—	—	0 5	0
6000	90 0	—	0	0 1
6200	—	—	0	0 3
6400	90 0	—	0	1 0
6600	—	—	0 5	2 5
6800	90 0	—	3 5	12 8
7000	—	—	25 5	23 1
7200	90 0	—	52 0	24 0
10000	90 0	—	—	9 5
15000	89 8	—	—	0 9
20000	85 7	—	—	2 6
25000	74 4	—	—	8 1
30000	1 8	—	—	0
35000	1 7	—	—	—
40000	—	—	—	—
45000	—	—	—	—

From Handbook of Chemistry and Physics, 23rd Ed , Chemical Rubber Publishing Company, Cleveland 1939

violet radiatioo made by the Corning Glass Company, is *Corex*. There are several distinct types of this glass, *Corex-A*, *Corex-D*, etc., depeodıng upon the chemical compositioo aod the iotended use of the glass. In Table 30 is given the transmissioo of various filters wbeo new.

IV. Fluorescence and Photosensitization

A. *Fluorescence.* When certain substances are irradiated with invisible ultraviolet rays, they emit colored light. Tbe transformatioo of the relatively short rays into radiation of longer waveleogths, lying in the visible zone, is known as *fluorescence.* Strictly speakiog, the term *fluorescence* should be confined to gases and liquids, sioce in the case of solids the emission of tbe visible light persists for an appreciable time after the excitiog ultraviolet radiatioo is cut off. Io some cases the emissioo of luminous eoergy may continue for hours, as for example, io the case of luminous paint of certain sulfides of calcium. In others, however, it lasts for only a small fraction of a secood after the excitiog rays are removed. The term *phosphorescence* should be used wbeo emission of radiaot eoergy occurs after irradiation, and *fluorescence* wheo the emissioo occurs during irradiatioo.

1. *Fluorescent and Phosphorescent Substances.* We shall not enter into a discussioo of the complex mechanism by which the effect of fluorescence is produced. In Tables 31 aod 32 various substances are presented with the cbaracteristic lumioous eoergy emitted by them wben ırradiated with ultraviolet radiation. It is not necessary that the shorter waveleogths of ultraviolet radiation be employed, nor, in fact, is it desirable to use the wavelengths that have profound biologic effects when employıng fluorescence as a diagnostic or an investigatıve agent

Almost any substance fluoresces to some degree at least Cbemically pure substances in general exhıbit fluorescence and phosphoresceoce only faintly. The impurities that mıgbt be present wıll influence to some degree the color of the emitted radıation. By a mixture of various materials, varıous colors can be obtained. The color of the fluorescence is generally dıluted, or

TABLE 31

FLUORESCENT SUBSTANCES

Substance	Solvent	Wavelength	Color
Anthracene	Alcohol	4000 A U 4300 4360	Violet
Eosine	Alcohol or Water	5890	Yellow
Esculine	Alcobol	4600	Blue
Fluorescein	Water (Alkaline)	5420	Green
Quinine Sulfate	Water	4370	Bluish Violet
Resorcin Blue	Water	6500	Red
Rhodamin	Water	5540	Yellow
Mercurochrome	Water	—	—

TABLE 32

PHOSPHORESCENT SUBSTANCES

Substance	Color
Wilemite	Yellow-green
Uranium Glass	Greenish yellow
Calcium Sulfide	Violet
Zinc silicate	Green
Calcite	Red
Barium Sulfide	Orange
Cadmium Compounds	Yellow
Calcium Tungstate	Light Blue

altered, by the body color of the substance. When studying the fluorescence of substances, it should be done in the absence of all visible light, so that reflection by the body of colors present in the visible radiation will not obscure or alter the color of the fluorescence.

2. *Filters for Fluorescent Examination.* The phenomenon of fluorescence can be excited by white light, and by radiation throughout the ultraviolet zone. The use of white light would, however, obscure the color of the fluorescent radiation. Therefore, it is necessary to absorb the visible radiation present in the spectrum of the source by means of a filter which is opaque to visible radiation, but which is transparent to the invisible ultraviolet rays. Furthermore, a source of radiation should be employed that does not contain an excessive component of thermogenic radiation, for it has been demonstrated that thermal radiation will quench phosphorescence. Ives and Luckiesh[13] have studied this effect of infrared radiation extensively. They also discovered that infrared causes a momentary flashing-up of the phosphorescence of zinc sulfide several minutes after excitation.[14] As Luckiesh states these phenomena can be utilized in signaling by projecting a beam of invisible infrared upon glowing zinc sulfide.[15]

The filter employed need not transmit strongly the entire gamut of ultraviolet radiation from 4000 A.U. to 2200 A.U., but, in fact, should transmit only those rays lying above the zone of biologic effect, that is, radiation of wavelength 3200 A.U. to 4000 A.U Various filters of such characteristics are available. An example is the Jena filter, known as UG 1, dark violet in color, obtainable from the Fish-Schurman Corporation, New York. In Table 33 is given the transmittance in per cent of this filter at various wavelengths throughout the ultraviolet, visible, and infrared zones, for filter thicknesses of 1 mm., 3 mm., and 5 mm. The transmission for 1 mm. thickness was taken from the Handbook of Chemistry and Physics, 23rd Edition, and that for the thicknesses of 3 mm. and 5 mm. was computed. For transmission of

[13] Ives, H. E., Luckiesh, M.: The Effect of Red and Infrared on the Degree of Phosphorescence in Zinc Sulfide. Astrophys. J. 34:3:173-196 (Oct.) 1911.

[14] Ives, H. E., Luckiesh, M.: The Influence of Temperature on the Phenomena of Phosphorescence in the Alkaline Earth Sulfide 36 4:330-343, 1912.

[15] Luckiesh, M.: Ultraviolet Radiation. D. Van Nostrand Co., New York, 1922.

other filters consult this reference. In order to have a high intensity of invisible ultraviolet radiation without the employment of a very high intensity source, it is necessary to use a thin filter A filter, 1 mm thick, of the glass on which data are given in Table 33, will transmit an appreciable amount of the available ultraviolet energy, while cutting off most of the visible radiation but permitting some violet light to pass, as well as some red. A quartz cell, 1 cm. deep, containing 20 per cent copper sulfate solution, will absorb the extreme red and also the unwanted infrared.

TABLE 33

TRANSMITTANCE OF U G 1 FILTER FOR FLUORESCENT EXAMINATION

Wavelength	Per Cent Transmittance for Thickness of		
	1 mm *	3 mm **	5 mm **
3020 A.U	17 0	0 5	0 014
3120	37 0	5 0	0 7
3340	69 0	33 1	15 8
3660	85 0	62	45
4050	8 0	0 05	0
4360	0	0	0
4800	0	0	0
5090	0	0	0
5460	0	0	0
5780	0	0	0
6440	0	0	0
7000	1 0	0	0
7750	34 0	4 0	0 4
8500	22 0	1 05	0 05
9500	11 0	0 13	0 002
10050	7 0	—	—
11050	5 0	—	—
13000	4 0	—	—
14050	4 0	—	—
16000	3 0	—	—
18000	4 0	—	—
20000	4 0	—	—
24000	11 0	0 13	0 002
30000	17 0	0 5	0 014

* Taken from Handbook of Chemistry and Physics, 23rd Ed

** Computed from data for 1 mm. as described in footnote * on page 265

3 *Non Medical Applications* Fluorescent phenomena have been employed rather extensively as agents for qualitative examination This method for identification of fluorescent substances presents, like x rays, two great advantages over all other forms of analysis, namely

First, the speed with which the examination can be accomplished

Second, the absence of any damage to the material undergoing test

The method can be applied to so many circumstances in which

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*In practice it is customary to determine the transmission of a sample of optical material for radiation by measuring the intensity of the incident radiation and the intensity of the transmitted radiation The ratio of the incident radiation to that of the transmitted radiation is called the *transmission* of the sample However the decrease in intensity of the radiation is due not only to absorption of radiation by the material but also to reflection of radiation at the first surface namely the air glass surface and at the second surface the glass air surface The loss by reflection is about 4 per cent at each of these surfaces The *transmittance* of the glass on the other hand is the ratio of the intensity of the radiation that actually enters the glass to the intensity of the radiation that reaches the opposite surface. It, therefore is a measure of the transmitting properties of the glass, whereas the transmission is determined by the transmitting properties of the glass and also by the reflecting properties of the two surfaces Since approximately 4 per cent is lost by reflection at each surface the transmission of a sample is about 92 per cent of its transmittance Therefore for example if the transmission of a sample is 0 80 for a thickness of 2 mm at the wavelength of 4600 A.U its corrected transmittance at this wavelength will be $\frac{0\ 80}{0\ 92}$ or about 0.871

To determine the transmittance and the transmission of this glass at the wave length of 4600 A.U but for a thickness of 5 mm instead of two mm we proceed as follows

Let T represent the transmittance of the glass I_0, the intensity of the radiation entering a layer of the medium and I the intensity reaching the opposite surface

Then $T = \frac{I}{I_0}$

But from Lambert s Absorption Law

$I = I_0 e^{-at}$ in which *a* is the absorption coefficient of this glass for the wave length considered and *t* the thickness of the glass in mm. Therefore, $T = \frac{I_0 e^{-at}}{I_0} = e^{-at}$

The symbol e represents a constant and equals 2 718— Then this equation may be written $T = 2\ 718^{-at}$ Taking logarithms of both sides of this equation we obtain

$$\log T = -at \log 2\ 718 = -at \times 0\ 434$$

Solving for *a* the absorption coefficient we obtain

$$a = -\frac{\log T}{0\ 434\ t}$$

(Footnote continued on next page)

fluorescent substances occur that only a few examples can be mentioned in this discussion

a Detection of frauds, counterfeits, or falsifications in bank notes, checks, valuable stamps, and important documents

b Rendering legible old writings that have become illegible through fading

c Testing of textiles for composition, process, inequalities of dyeing, etc

d Differentiation between genuine and imitation substances or between natural and synthetic products

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(Footnote to table 33 continued)

Substituting the values given above, namely, $T=0\ 871$ and $t=2$ we obtain for a

$$a=-\frac{\log 0\ 871}{434\times2}=-\frac{(9\ 94-10)}{868}=\frac{060}{868}$$

Let us now, knowing the absorption coefficient of this glass determine what the transmittance will be at the wavelength 4600 A U for a thickness of 5 mm Substituting in the equation $\log T=-0\ 434\ at$ we obtain

$$\log\ T=-0\ 434\times\frac{060}{868}\times5=-0\ 15=9\ 85-10 \text{ or}$$

$$T=\ 708$$

The transmission which is 92 per cent of the transmittance, will be $92\times\ 708$ or 651

The values in Table 33 for the thickness of 1 mm are corrected for reflection and therefore represent the transmittances at the various wavelengths The values given in that table are then substituted directly in the equation for transmittance and the absorption coefficient computed for each wavelength After determining this coefficient for each wavelength the transmittance of the filter for the thicknesses of 3 mm and 5 mm is readily computed for the various wavelengths An example of the method of computing the transmittance of the filter for thicknesses of 3 mm and 5 mm at the wavelength 3340 A U follows

Thickness = 1 mm, $\lambda=3340$ A U transmittance = 69 per cent

Then $\log_{10} 0\ 69=-\ 434\times a\times1$, and $a=\frac{9\ 84-10}{-\ 434}=\frac{160}{434}$

For 3 mm $\log_{10} T=-\ 434\times3\times\frac{160}{434}=-\ 48=9\ 52-10$, or

$$T=\ 331 \text{ or } 33\ 1 \text{ per cent.}$$

For 5 mm $\log_{10} T=-\ 434\times5\times\frac{160}{434}=-\ 80=9\ 20-10$, or

$$T=\ 158 \text{ or } 15\ 8 \text{ per cent.}$$

e. Rapid detection of adulteration or substitution in foodstuffs; examination of moulds, etc.

f. Detection of those fish tissues which are rich in Vitamin A.[18]

4. *Medical Applications.* At present the application of fluorescent phenomena has a limited use in the field of medicine. It can be used as follows:

a. To differentiate between diseased and normal tissues.
b. To reveal ringworms, which fluoresce a vivid green
c. To reveal old scars or x-ray burns.
d. To differentiate between devitalized and living teeth; devitalized teeth fail to fluoresce, while living teeth fluoresce to a brilliant whiteness.
e. To identify bacterial cultures.

In the future, additional important uses may be discovered in this comparatively new field. For example, a recent note in *Time*, June 15, 1942, page 35, reports the use of fluorescence to determine whether or not to amputate in certain conditions. This procedure was described recently by Lange and Boyd at the New York Medical College. According to the report in *Time*, fluorescein is intravenously injected into the arm of the patient having a gangrenous foot or strangulated hernia. The room is darkened, and ultraviolet radiation is directed onto the gangrenous area. The fluorescein should make a circuit of the patient's blood stream in 20 seconds. According to Lange and Boyd, if the foot or protruding gut is still vital and receiving an adequate supply of circulating blood, it will fluoresce yellow-green. Then it is safe to reduce the hernia, or stimulate circulation in the leg. But if circulation to the part is occluded, the leg or hernia remains dark on irradiation with ultraviolet. When this is the case, there must be immediate recourse to surgery. According to the report quoted, Lange and Boyd believe that by this test unnecessary surgery may be avoided.

B. *Photosensitization.* By the use of fluorescent substances the effectiveness of radiation in producing certain effects may be enhanced. This effect of fluorescent substances is known as

[18] Science, 95 12 (April 17) 1942.

photosensitization A critical evaluation of the merits and limitations of photosensitization by fluorescent substances in ultraviolet therapy has been presented by Krusen[7] His discussion of the subject follows

An individual may be sensitized to ultraviolet rays by the internal administration of fluorescent substances Frequently it has been the practice in Germany, to administer eosin (in 0 2 gm doses) prior to ultraviolet irradiation for rickets This practice was begun after the World War of 1914 1918, when it was found necessary to treat a large number of undernourished children in a limited amount of time This procedure shortened the length of time required for each treatment The method is little used today and cannot be advocated, at least until it is better developed Following the injection of 3 to 10 mg of hematoporphyrin hydrochloride in alkaline solution at intervals of a few days, into rachitic rats, basement room light will heal the bone lesions and improve calcification

Rachitic patients can be cured with a much shortened course of irradiation with the quartz lamp if 0 1 gm of eosin pulverized with 0 2 gm of cane sugar is administered daily With eosin, only 100 minutes of exposure are required, whereas without it, 210 minutes of exposure are necessary It has been strongly recommended that photosensitizing mixtures be used for various diseases characterized by decalcification, it being suggested that there be used an intravenous injection of a poly sensitizing mixture '

Certain investigators have demonstrated that if very small amounts of eosin, which is fluorescent, are added to solutions, subsequent ultraviolet irradiations of these solutions are more highly germicidal in action on the solution than when eosin has not been added In a similar manner fluorescein and other fluorescent substances in solution will increase the germicidal action of ultraviolet rays in that solution It is likewise thought that fluorescent substances in the skin, such as quinoidine, when irradiated may become bactericidal It is possible that application of fluorescent substances to the surface of the skin may increase the bactericidal power of ultraviolet radiation applied over that surface This procedure has not yet been *sufficiently developed for general clinical* use Good results have been recorded in treatment for psoriasis by use

[7] Krusen F H Physical Medicine W B Saunders Co Philadelphia 1941

of combined applications of crude coal-tar ointment and ultraviolet irradiation, with the thought that "coal-tar acts as a sensitizing agent for the light."

Photosensitization may result from the ingestion of certain foods and also certain drugs, such as the sulpha compounds now so widely used in various infectious diseases. Foods that will act as a photosensitizer for one patient may not for another. Care must therefore be exercised to determine whether a patient, due to drugs or to foods, is abnormally sensitive to ultraviolet radiation. In the discussion of technic, the routine procedure to be followed to determine a patient's sensitivity to ultraviolet radiation will be outlined.

V. Biologic Effects The biologic effects of ultraviolet radiation have been extensively studied. Some have been well established, together with the relative effectiveness of the different wavelengths of ultraviolet radiation in producing them. These effects provide the basis on which rational therapeutic application of ultraviolet is founded.* Other effects may be produced, but such possible effects should be critically evaluated before basing therapeutic application on them.

According to Hess and Poncher:[38]

1. The beneficial effects are brought about by the stimulation of the nerve endings in the skin with resultant functional changes in the autonomic nervous system.

2. The rays produce a general systemic reaction by penetration and absorption in the capillaries of the corium

3. The sterol in the skin is rendered photoactive by radiation It has been definitely shown by various investigators that irradiated animal and human skin is antirachitic and that this action is therefore independent of the intact nervous or circulatory system.

* A recent evaluation of the therapeutic indications for ultraviolet irradiation has been prepared and published by the Council on Physical Therapy of the A.M.A : *The Therapeutic Value of Ultraviolet Radiation* J.A.M.A., 120: 620, 1942, 121 126, 1943, and 121.513, 1943

[38] Hess, Julius H., Poncher, Henry G : Principles and Practice of Physical Therapy. 1: W. F. Prior Co., Hagerstown, Maryland, 1936.

The known and established effects of ultraviolet radiation are essentially photochemical, and the effects which are produced depend on the particular wavelengths employed The relative effectiveness of radiation of different wavelengths in producing these effects can best be expressed by means of graphs, in which the degree of the effect observed is measured vertically against a horizontal scale of wavelengths This method is employed in the following discussion

A *Production of Erythema* Sometime after irradiation, a red ness appears in the irradiated skin of the subject This redness is called an erythema Not all ultraviolet wavelengths are equally effective in producing this effect, nor is the time elapsing between the irradiation and the first appearance of the erythema the same for all wavelengths

In Fig 84, taken from Hausser,[10] the degree of redness or erythema of skin at various periods after irradiation with different wavelengths of ultraviolet radiation is shown The same intensity and the same time of irradiation was employed for all wavelengths used, that is to say, the same total energy was administered at the various wavelengths studied Through the plotted points smooth curves were drawn, giving the series of curves shown in the figure already referred to

It is to be noted that the erythema response curve has two maxima, one at about 3000 A U, and the second at about 2500 A U Furthermore, the maximum degree of reddening of the skin due to radiation of wavelength 2500 A U appears in about 6 hours after irradiation and then begins to fade, disappearing completely at the end of six days, whereas the maximum degree of reddening due to 3000 A U does not develop before a day after irradiation, persisting at this level for 3 days and at the end of 10 days still being 66 per cent of its maximum The erythema, therefore, due to irradiation with a lamp having its maximum ultraviolet output at about 2500 A U, such as the so called "cold quartz" lamp, should develop early after exposure and also fade

[10] Hausser K. W Einfluss der Wellenlange in der Strahlenbiologie, Licht biologie und Lichttherapie, edited by Hans Meyer Urban und Schwartzen berg Berlin, 1928

away within a few days On the other hand, the erythema due to a source emitting most of its erythemogenic radiation at 3000 A U, as the sun, should develop slowly, but persist for a relatively long period of time The evanescent character of the erythema due to radiation from a "cold quartz" lamp, as com-

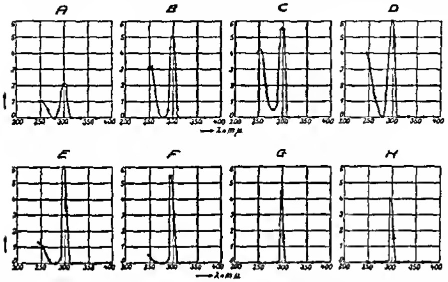


FIG. 84 Degree of erythema for different wavelengths of ultraviolet radiation at various periods after exposure A 2 5 hours, B, 4 5 hours, C, 6 5 hours, D, 1 day, E 3 days, F, 4 days, G, 6 days, H, 10 days (From Hausser, K. W Einfluss der Wellenlange in der Strahlenbiologie, Lichtbiologie und Lichttherapie, edited by Hans Meyer, Urban and Schwartzenberg Berlin, 1928)

pared with the erythema produced by solar radiation, is well known to users of ultraviolet radiation

Irradiation with a hot quartz mercury arc lamp will produce both types of erythema, since the radiation from that type of lamp contains strong emission lines in the neighborhood of both 3000 A U and 2500 A U

The relative effectiveness of different wavelengths in the production of erythema has been fairly well determined While results obtained by different observers as to the relative effectiveness of radiation in the region of 2500 A U vary widely, results

obtained by them agree well as regards the fact that two maxima exist, one at about 2500 A U and another at about 3000 A U Fig. 85, taken from Taylor,[20] shows the results of five researches The heavy curve, determined by Coblentz, Stair, and Hogue,[21] represents approximately the average

According to the results shown in this figure, the line 2967 A U in the mercury spectrum appears to be the most effective wave-

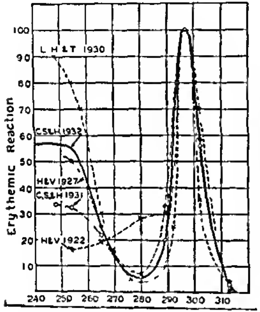


FIG 85 Relative spectral erythemic reaction of the human skin to equal amounts of radiant energy at various wavelengths H and V—Hausser and Vahle L, H, and T—Luckiesh, Halloday, and Taylor C, S, and H—Coblentz, Stair, and Hogue (From Bureau Standards J Research 8 544 1932)

length in producing erythema per unit of energy—that is to say, to produce a given final degree of erythema apparently less energy is required at this wavelength than at any other wavelength However, the relative effectiveness of radiation at 2500 A U and 3000 A U. in producing an erythema depends upon the

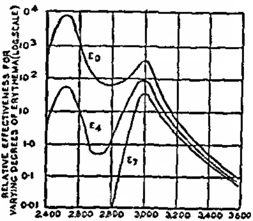
[20] Taylor, A H. The Measurement of Erythemal Ultraviolet Radiation J Optic Soc America 23 60 (Feb) 1933

[21] Coblentz W W, Stair, R., and Hogue, J M The Spectral Erythemic Reaction of the Untanned Human Skin to Ultraviolet Radiation Bureau of Standards J Research. 8 544, 1932

degree of erythema to be produced The two maxima of the erythema response curve are not of equal value in a photobiological sense according to Seitz [22]

The erythema curve should therefore not be reproduced in its form as usually drawn, but graduated according to the grades of skin reddening In Fig 2 [Fig 86] spectral curves of action are shown for the minimum erythema, for a middle degree erythema, and for strong sunburn The

FIG 86 Relative spectral erythema efficiency for the minimum perceptible erythema (E_0) middle degree erythema (E_4), and sunburn (E_7) (From Seitz E. O Ultraviolet Radiators and Their Biologic Evaluation British Journal of Physical Medicine Vol 11 p 10 Feb 1937)



relative erythema effectiveness is drawn on a logarithmic scale since for (e g) the minimum erythema (E_0), the relative effectiveness of wavelengths 2500 3600 A U is about 100 000 1 The maximum at about 3000 A U is taken as = 100 for the middle erythema (E_4 in Hausser and Vahle s definition) and the erythemogenic activity of other wave lengths, and also for other degrees of erythema is referred thereto The curve for E_4 in Fig 2 [Fig 86] corresponds in its course to the erythema curve of Coblentz as shown in Fig 1 [Fig 87, page 282], from which it follows that Coblentz must have chosen something corresponding to this mean grade of erythema as a criterion

It is seen from this diagram that in the production of the minimum erythema (E_0), short waved radiation of about 2500 A U has an action about 100 times stronger than the U V radiation about 3000 A.U, that as regards a mean degree of erythema (E_4) both maxima are almost equal, whereas sunburn is exclusively evoked by the spectrum region about 3000 A U

[22] Seitz E. O Ultraviolet Radiators and Their Biologic Evaluation The British J Physical Med. 11 179 (Feb) 1937

Work done at Cornell University by Maughan[23] indicates that the wavelength 2968 A U is very important in the prevention and cure of rickets in chickens, and presumably the same would apply to rickets in children

Concerning the mechanism responsible for the production of erythema, Laurens states [24]

> Ultraviolet irradiation forms or liberates active substances in the skin which are responsible for the erythemal response and for pigmentation The structural changes are almost entirely limited to the stratum mucosum and the erythemal response seems due to the photochemical decomposition of a constituent of these cells with the liberation of active reaction products These diffuse to the region of the minute vessels of the subpapillary venous plexus of the corium and lead to vasodilation The active substance is probably a typical protein or a simple derivative The photooxidation of typical proteins with wavelengths from 2350 to 3150 Angstroms leads to the formation of proteoses and similar products It is a plausible hypothesis that the active substance is a derivative of the proteins of the cells of the stratum mucosum, that it is an H substance, that is, a substance with some of the functions of histamine, if not histamine itself, and that it is in the form of an H colloid (Mitchell 1938) It is reasonable to believe that erythema is a sequel to injury to the prickle cells produced by wavelengths shorter than 3150, and that this injury is of the nature of coagulation or denaturation of the protein of the prickle cells of the epidermis Blum believes that the simplest explanation is that the erythemic mechanism is composed of two rather distinct parts The first is a photochemical reaction which determines the amount of radiation necessary to produce the erythemal response, which like most photochemical reactions has a low temperature coefficient This reaction takes place principally in the prickle cell layer, but sets off other reactions which result in the production of substances which cause the dilation of the minute vessels in the papillary layer It is these secondary reactions which occupy the latent period

There is a belief that infrared radiation may, under certain

[23] Maughan G H Ultraviolet wavelengths valuable in the cure of rickets in chickens Amer J Physiology 87 381 Dec 1928

[24] Laurens, Henry The Physiologic Effects of Radiant Energy Arch Phys Therapy 23 3 (March) 1942

conditions, enhance the effect of ultraviolet radiation; and under other conditions, diminish the effect: acting in the first case as a synergistic agent, and in the second as an antagonistic agent. It is true that infrared rays will have an influence on fluorescence, as has been pointed out, and it is reasonable to assume that the heat produced by the absorption of infrared rays may have an effect on the speed of photochemical reactions.

A number of workers have observed that if ultraviolet irradiation is preceded by irradiation with infrared rays, the effect of the ultraviolet irradiation is enhanced.[25] Hill, according to Krusen,[26] believes that the biologic action of ultraviolet rays is accelerated by the heating effect of infrared and luminous rays. The synergistic effect of infrared and visible radiation seems to be greater if administered before irradiation with ultraviolet rays than if administered concurrently. In most instances then, according to Krusen, infrared irradiation should precede ultraviolet irradiation rather than be administered in excessive amounts concurrently. Further, Rosewarne[25] states that the mild erythema provoked by ultraviolet irradiation may be suppressed by subsequent infrared irradiation.

However, concerning the possible antagonism of radiation of different wavelengths, Blum,[27] who has critically evaluated the available evidence, states:

> Much has been published about the supposed antagonism of different wavelengths, but the subject seems shot through with error and misunderstanding. There is no theoretical reason for believing that specific wavelengths are antagonistic to other specific wavelengths yet the idea that infrared radiation tends to oppose visible or ultraviolet radiation is current in some places.

B. *Production of Pigmentation.* Contrary to popular belief, the presence of melanin in the skin does not protect the human

[25] Rosewarne, D D : A Textbook of Actinotherapy, with Special Reference to Ultraviolet Radiation. C. V. Mosby Co, St. Louis, 1928

[26] Krusen, F. H.: Physical Medicine. W. B. Saunders Co, Philadelphia, 1941.

[27] Blum, H. F.: Photodynamic Action and Diseases Caused by Light. Reinhold Publishing Corporation, New York, 1941.

organism from ultraviolet rays by acting as an absorber of such rays, since ultraviolet rays do not penetrate to the basal epidermal layers, in which the melanin is situated (See *Transmission and Absorption*, page 254) The deposition of melanin will, however, afford protection against the relatively deeply penetrating infrared and visible rays Krusen[28] observes that a thickening of the horny layer, following repeated exposure, provides the protection against excessive ultraviolet radiation which has been attributed to the tanning that results from exposure to ultraviolet radiation

Laurens[29] explains pigmentation on the basis of cell injury, since it is generally preceded by an erythema The migration of the pigment from the undamaged basal cells into the injured cells of the more superficial epidermis is due, according to him, to the trophic action of some chemical substance set free by the injured cells Laurens believes the formation of new pigment in the basal cells may be explained by the action of some substance elaborated by the injured cells

The difference in pigmentation produced by ultraviolet radiation of wavelength 2500 A U and 3000 A U is discussed as follows by Seitz [30]

An erythema produced by wavelengths around 2500 leaves scarcely any, or at most only an inconsiderable pigmentation whereas the erythema produced by 3000 A U results in strong pigmentation Frankenburger s brilliant suggestion offers a plausible explanation of these phenomena the substance which produces pigment is tyrosine which is deposited in the upper layers of the epidermis and is protected by a horny layer about 25μ thick It follows that the absorption curve of tyrosine must be multiplied by the absorption curve for the horny layer of the skin The absorption spectrum of tyrosine thus modified then shows a striking agreement with the skin erythema curve Histidine is regarded as a second important material in the skin reaction and its photochemical change into histamine which as known produces a vivid

[28] Krusen F H. (see preceding reference)

[29] Laurens Henry (see preceding reference)

[30] Seitz E O Ultraviolet Radiators and Their Biologic Evaluation British Jour Physical Med 11 179 (Feb) 1937

erythema when introduced into the skin, even in minimal quantities, is conceivable as at least a by-product or intermediary transition product. This histidine-histamine change occurs only with wavelengths below 2700 A.U. and according to this the primary erythema reaction would pertain only to the U-V of shorter wavelength. The erythemal activity of the longer-waved U-V can be explained by assuming an incursion of minute amounts of histamine into the outer layers in consequence of cell-destruction through the longer-waved U-V there absorbed. These considerations satisfactorily explain both the diverse erythema and pigmentation actions of the two maxima on the erythema curve.

The most effective wavelengths for producing pigmentation appear to lie in the spectral band 2900 A.U. to 3300 A.U. Sunlight produces the most perfect pigmentation, and its radiation does not extend below 2900 A.U. Furthermore, sunlight filtered through glass, which reduces materially the intensity of solar radiations of wavelengths shorter than 3300 A.U., produces very little pigmentation. Pigment formation is dependent on individual factors, race, coloring, constitution, and body function. It can be used as an idex in treatment. It is also a measure of adaptation, since pigment formation, horny layer thickening, and chemical alterations of the skin cell proteins run parallel.

C. *Activation of Ergosterol.* Heilbron, Kamm, and Morton[11] believe that in order to obtain a high yield of vitamin D in irradiated ergosterol, only rays longer than 2700 A.U. should be used, because of photo-decomposition of the vitamin by the shorter wavelengths. They found from spectroscopic examination that the wavelengths absorbed by ergosterol are 2930 A.U., 2810 A.U., and 2700 A.U. These wavelengths are then, obviously, the wavelengths effective in activating ergosterol, for it is only those wavelengths of radiation which are absorbed that can be effective in bringing about photochemical changes. Heilbron and his associates observed that these absorption bands disappeared in proportion to the gain in anti-rachitic potency. As these absorption bands disappeared, a new absorption band developed at 2470 A.U. This

[11] Heilbron, I. M., Kamm, E. D., Morton, R. A.. Absorption Spectrum of Cholesterol and Its Biological Significance with Reference to Vitamin D. Biochem. J 21 78, 1927

new absorption band is associated with the presence of vitamin D and if the activated ergosterol is irradiated with radiation of the wavelength 2470 A U, photo decomposition of vitamin D results, with the formation of other substances of a possible toxic nature

D *Effect on Calcium and Phosphorous Metabolism* Through photochemical effects of ultraviolet radiation on some cholesterol derivative present in the skin acting as a precursor, vitamin D is formed and in some manner absorbed, increasing the rate of calcium and phosphorous metabolism The wavelengths of radiation found most effective are approximately the wavelengths of the absorption bands of ergosterol However, it must not be concluded, therefore, that the provitamin substance present in the skin is ergosterol In fact, Harris, quoted by Krusen,[32] states that ergosterol has never been proved to be present in animal tissue, being a plant sterol In the opinion of Laurens,[33] it seems that 7 dehydrocholesterol is the significant provitamin D of the skin

It seems generally agreed that the wavelengths most effective in curing rickets, and hence presumably most effective in promoting calcium and phosphorous metabolism, are in the region between approximately 3120 A U and 2650 A U The favorable influence of ultraviolet radiation of wavelengths in the spectral zone, 3120 A U to 2650 A U, on calcium and phosphorous metabolism, indicates in general the usefulness of such radiation in the treatment of conditions due to calcium deficiency

E *Bactericidal Effect* The bactericidal effect of ultraviolet radiation has been known for many years Over 60 years ago, Downes and Blunt[34] demonstrated that sunlight killed bacteria, and showed that the action was associated chiefly with the shorter wavelengths

The extensive work that has been done recently in this field has demonstrated that radiation in the spectral region of the

[32] Krusen F H Physical Medicine W B Saunders Co Philadelphia 1941

[33] Laurens H The Physiological Effects of Radiant Energy Ann Rev Physiol 3 21 1941

[34] Downes and Blunt Proc Roy Soc 26 488 1877

mercury line of 2537 A.U is most effective in the killing of B. Coli. Hence, a low pressure mercury glow discharge lamp, which emits approximately 95 per cent of its ultraviolet radiation at the line 2537 A.U., should be a powerful bactericidal agent. Using such a generator, Koller[33] has investigated the potency of its radiation in killing bacteria in air and on surfaces. He found that a lamp of this type, taking 15 watts and emitting 25 microwatts per square centimeter of 2537 A U. radiation at 1 meter from the lamp, will kill 97 to 99 per cent of B. Coli suspended in air at a distance of 24 inches in 10 seconds. Such a lamp, he found, will kill B. Coli on the surface of agar at a distance of 10 inches in 20 seconds. Koller found that the Bunsen-Roscoe reciprocity law applied to the killing of bacteria throughout a wide range of intensities. He also found that for practical purposes the effect of temperature may be neglected.

The lethal dose of 2537 A.U. radiation for different bacteria and spores was found by Koller to vary widely, as would be expected, being 6600 microwatt seconds per square centimeter for B. Coli on agar, and 45 times that for black mold spores.*

From Koller's experiments it may be concluded that ultraviolet radiation of wavelength 2537 A.U. is a powerful bactericidal agent, *if the bacteria are directly exposed to the radiation, but that the effectiveness is greatly reduced by even such a slight shielding as is offered by a film of grease.*

In view of the fact that a thin film of grease or other organic matter completely protects bacteria from the bactericidal effect of ultraviolet radiation of wavelength 2537 A.U., no direct effect can be expected on deep-lying bacteria when irradiating a lesion

[33] Koller, Louis Bactericidal Effects of Ultraviolet Radiation Produced by Low Pressure Mercury Vapor Lamps Jour Applied Physics. 10 9:624-630 (Sept) 1939.

* The survival ratio of bacteria when subjected to some lethal agent has been shown to be an exponential function of time of the form

$$N = N_o e^{-kIt};$$

where N = number of organisms surviving at any time t, N_o = the number of organisms at time $t = o$, k = a constant depending upon the susceptibility of the organisms to the radiation, and I = the radiation intensity, and e = 2 718–, the base of the natural system of logarithms.

with such radiation Ultraviolet radiation of longer wavelength (3000 A U) has a somewhat greater penetrating power, but has only a negligible bactericidal effect It appears reasonable to assume that any bactericidal effect, produced below the surface of tissue by irradiation with ultraviolet, is due to secondary effects of such radiation To destroy bacteria, energy must be absorbed The absorption characteristics of bacteria are not greatly different from those of normal tissue cells Hence, it is obvious that radiation, capable of being absorbed strongly by bacteria, will be absorbed strongly by the tissue cells intervening between the bacteria and the source of radiation Such tissue cells would, therefore, protect the bacteria beneath them

Any source of radiation, emitting strongly in the zone 2400 A U to 2800 A U, can be used as a bactericidal agent for the destruction of *accessible* bacteria

A great deal of work has been done investigating the potentialities of ultraviolet radiation as a means of sterilizing air in operating rooms, hospitals, and schoolrooms According to Wells and others, air borne infections can be controlled by this means The literature has become extensive on this subject For those interested in pursuing this subject further, the following references are presented Each of the articles contains additional bibliographies, which may be consulted

Wells, W F, Wells, M W Air Borne Infection J A M A 107 1805, 1936

Wells, W F, Wells M W Measurement of Sanitary Ventilation Am J Pub Health 28 343, 1938

Koller, L R Bactericidal Effects of Ultraviolet Radiation Produced by Low Pressure Mercury Vapor Lamps J Applied Physics 10 624, 1939

Wells, W F, Wells, M W, and Mudd, Stuart Infection of Air, Bacteriologic and Epidemiologic Factors Am J Pub Health 29 863, 1939

Robertson, E C, Doyle, M E, Tisdall, F F, Koller, L R, and Ward, F S Air Contamination and Air Sterilization Am J Dis Children 58 1029, 1939

Wells, W F Apparatus for Study of Experimental Air Borne Disease Science 91 172, 1940

Wells, W. F.: Bactericidal Irradiation of Air: Part I, Physical Factors. J. Franklin Institute. 220:3, 1940.
Andrews, C. H.: Control of Air-Borne Infection in Air-Raid Shelters and Elsewhere. Lancet 2:770, 1940.
Koller, Lewis R.: *Killing Germs with Ultraviolet*. Wallerstein Laboratories Communications. 4:183, 1941.
Wells, W. F., Wells, M. W., and Wilder, T. S: The Environmental Control of Epidemic Contagion. I. An Epidemiologic Study of Radiant Disinfection of Air in Day Schools. Am. J. Hygiene. 35:97, 1942.
Wells, W. F.: Radiant Disinfection of Air. Arch. Phys Therapy. 23: 143, 1942.

F. *Summary*. Seitz[26] has summarized, in the form of spectrum action-curves, the various established effects of ultraviolet radiation. Fig. 87. In addition to action-curves for the effects discussed in the foregoing paragraphs, which are the effects on which clinical application is primarily based, are also action-curves for growth restriction of tissue cultures, for albumen coagulation, and for hemolysis. To quote Seitz:

> The effects which sound so alarming, such as growth restriction, cell-destruction, albumen coagulation and haemolysis, diminish in significance as soon as one remembers the filtration of incident energy through the resistant horny layer and the layers of cuticle. If, taking the skin erythema as a guide, over-dosage is avoided, then cell-destruction will not go beyond a stimulus which is mild and desirable on cosmetic grounds for regeneration of the skin. The autogenous protein effects likewise aroused are furthermore capable of activating the entire metabolism and increasing nervous and muscular vigour. Using rational dosage we at the same time avoid another undesirable effect ascribed to the short rays: From the experiments of van Wijk and Reerink it might be argued that irradiation with 2500 A.U. damages the Vitamin D formed from ergosterol or creates noxious substances in such amounts that irradiation with these wavelengths would need to be avoided. The tests made have, however, shown that by using small doses the required vitaminization occurs even with U-V-R of 2500 A.U. and that the noxious effect only begins with doses which in practice, if the erythema curve be taken as a guide, are never applied Noxious effects are only to be feared with sources of rays which have an absolute predominance of

[26] Seitz, E. O. (see preceding reference, page 276).

this short U V, such as the low pressure mercury lamp in quartz or transparent glass (the cold quartz lamp) In fact, no failure of activation has ever occurred when using U V sources having a good energy distribution between 2500-3100 A U Furthermore not one single instance is reported of toxic effects from short waved U V when irradiating men or animals as opposed to the effects observed when irradiating vitaminized drugs in which (owing to the lack of a guiding erythema)

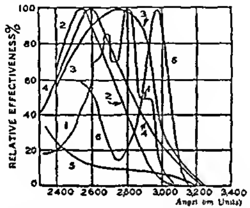


FIG 87 Spectrum action curves for various biologic effects (From Seitz) 1 Ergosterol absorption (van Wijk and Reerink Strahlentherapie 40 739 1931) 2 Bactericidal Action (B Coli) (Ehrismann and Noethling Z Hyg 132 597 1932) 3 Growth Restriction of Tissue Cultures (E Mayer Strahlentherapie 39 148 1931) 4 Albumen Coagulation (Luckiesh Artificial Sunlight D Van Nostrand Co New York 1931) 5 Hemolysis (C Sonne Strahlentherapie 28 45 1928) 6 Erythema Curve (Coblentz Stair and Hogue Bureau of Std J Research 8 541 1932)

the dosage was excessive Against the conjunctivitis evoked by short waved U V it is easy to take simple precautions during therapeutic exposures by such measures as closing the eyes or wearing close fitting goggles

VI TECHNIC OF APPLICATION From the foregoing discussion on the generation of ultraviolet radiation, its transmission and absorption, and its biologic effects, you have learned that *it is the* invisible rays of wavelength less than 3200 A U that must be employed for ultraviolet therapy

The entire ultraviolet zone of radiation extending from 4000 A.U., the limit of the visible spectrum, to 1850 A U., the limit of transmission of quartz, has been subdivided into various zones. In Fig. 88 are given the subdivisions in common use and their approximate wavelength limits, together with the approximate zones of biologic effects. In our opinion, the majority of classifications are based on arbitrary standards having no definite relationship to biologic phenomena. The spectral range of ultraviolet radiation employed in therapeutics extends from approximately 3200 A.U. to 1850 A.U., the limit of transmission of quartz, but for all practical purposes extends only to about 2200 A.U., since radiation of wavelength shorter than this, generated by sources in common use, has a negligible intensity. It is suggested that two subdivisions be employed: non-therapeutic, 4000 A.U. to 3200 A U.; and therapeutic, 3200 A U. to 2200 A U. The upper limit of 3200 A.U. for the therapeutic zone seems logical, since at this wavelength the spectral action-curves given in Fig. 87 indicate the cessation of all the well-established biologic effects upon which therapeutic application is based.

The clinical application of ultraviolet radiation must be based on a consideration of a number of factors, such as the patient's sensitivity, the type and the intensity of the radiation, and the therapeutic effect to be produced.

A. *Dosage.* Let us discuss the matter of dosage from the viewpoint of these factors. It has been repeatedly brought out in the preceding paragraphs that to produce an effect the absorption of energy is required. Furthermore, the threshold quantity of energy to produce a given effect to a given degree will vary between individual patients. Everyone has observed that different individuals will not respond to the same degree to the same exposure to sunlight. Not only, therefore, is it necessary, when irradiating a patient to produce a given therapeutic effect, to know what type of radiation is most effective, but also to know the intensity of the radiation used and the patient's susceptibility. Knowing these factors, a technic can be established for that patient.

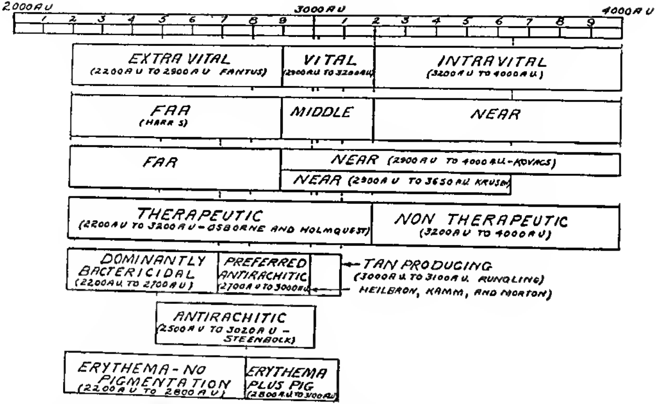


FIG 88 Chart showing the various subdivisions into which ultraviolet radiation has been divided their approximate wave length limits and the spectral zones of various biologic effects

1 *Source of Radiation* The source of radiation employed should emit radiation of adequate intensity in the zone of wavelengths less than 3200 A U, *the therapeutic zone* If primarily a heating effect with incidental beneficial ultraviolet effects is to be obtained, a source relatively weak in intensity in the thera peutic band, but emitting a preponderance of its radiation in the thermogenic range, 5000 A U to 15,000 A U, should be chosen

The sources in common use are

a Hot quartz mercury arc

b Carbon arc with various types of carbons

c Low pressure mercury glow discharge (so called *"cold quartz"*)

Of the foregoing, the first and third generate primarily ultra violet radiation The spectral distribution of the radiant energy emitted by a carbon arc will depend upon the composition of the carbon electrodes as already explained

a *Spectral Distribution* The spectral distribution of the radiant energy emitted by various types of sources has already been discussed The relative efficiency of these different sources in producing various biologic effects has also been considered In Table 34 information on the three sources, mentioned in the preceding paragraph as being in common use, is given in general terms, which should prove of assistance in selecting the proper source for the irradiation of a patient

b *Intensity of Ultraviolet Radiation* All lamps emit a mixture of radiation The output of therapeutic ultraviolet radiation (that is, radiation of wavelength less than 3200 A U) has been expressed in various units of measurement Radiometers of various types have been employed They can be divided into two classifications, selective and non selective in their response to radiation A non selective radiometer is one that responds equally to all wavelengths of radiation The response, therefore, of such a radiometer will be proportional to the incident intensity, regardless of the wavelength of the radiation A selective radiometer, on the other hand, does not respond equally to all wavelengths

The response of such a radiometer to radiation is a measure of the efficacy of the source under measurement in producing the effect upon which the operation of the radiometer is based Therefore, its response is not necessarily a measure of the efficacy of the source in producing biologic effects whose spectral action-curves are different from the spectral response curve of the

TABLE 34

Source	Spectral Distribution			Field of Usefulness
	Therapeutic Ultraviolet Radiation	Visible Radiation	Near Infrared Radiation	
Hot Quartz Mercury Vapor Arc	High	Moderate	Moderate	Complete range of ultraviolet therapy
Carbon Arc Sunshine Carbon	Low	High	High	Primarily for heat therapy with minimal concurrent ultraviolet effects.
Therapeutic C Carbon	High	High	High	Complete range of ultra violet therapy if heat is not contra indicated
Cold Quartz	High 95% of total at 2537 A U	Low	Low	Bactericidal (Accessible bacteria)

radiometer If the radiometer is so constructed that its response to the wavelengths within the therapeutic zone of ultraviolet approximates the erythemal response curve, then the response of the radiometer to the radiation from a source will be approximately proportional to the erythemogenic effect of the radiation from that source Similarly, if the response curve of the radiometer should approximate the bactericidal spectral action curve,

the measure of intensity obtained with the radiometer will be a measure of the bactericidal efficiency of the source. Similarly, with other spectral action-curves. Therefore, in order to measure the useful output intensity of a source of ultraviolet radiation with a selective radiometer, the use to which the radiation is to be put should be known, and a radiometer with appropriate spectral response be chosen In Table 35 are given some of the various types of radiometers that have been employed.

TABLE 35

Radiometer	Response
1. Non-selective	
a. Thermal methods	
(1) Thermopile with spectrometer	Equally to all radiation
(2) Bolometer with spectrometer	Equally to all radiation
2 Selective	
a Photo-chemical methods	Selective, depending upon solution
b Photo-electric methods	Selective, depending upon metal
c. Thermal methods	
(1) Thermopile with filters	Selective, filters do not have sharp cutoff
(2) Bolometer with filters	Selective, filters do not have sharp cutoff

Further information on the measurement of radiation can be obtained from various publications For convenience, a few references to such publications follow, each of which contains further references:

1. Coblentz, Stair and Hogue: A Balanced Thermocouple and Filter Method of Ultraviolet Radiometry with Practical Applications. Res Paper No. 370, Bureau of Standards J. Research, Vol. 7 (Oct) 1931.
2. Harris, D. T.: The Technique of Ultraviolet Radiology. Blackie and Son, Ltd , London and Glasgow, 1940.

A unit known as the *Finsen Unit* has been suggested by Coblentz, in which the intensity of ultraviolet radiation might be

expressed This unit corresponds to 10 microwatts per square centimeter of homogeneous radiation of wavelength 2967 A U and is designated as the erythema unit (E U) by the Council on Physical Therapy Concerning the selection of this unit, the Council states [37]

> Physiologic experiments show that for practical purposes the wavelength of maximum erythematogenic action may be taken as the emission line of homogeneous radiation of mercury vapor at 2,967 angstroms, a wavelength present in many sources of ultraviolet radiation
>
> This emission line has an erythematogenic efficiency which may arbitrarily be plared at 100 per cent relative to the rest of the spectral erythemic response No other wavelength or group of wavelengths has such a high efficiency in generating an erythema Hence the emission line of homogenous radiation at 2,967 angstroms is a natural standard for evaluating sources of heterogeneous ultraviolet radiation
>
> The intensity and the erythematogenic action of the emission line of mercury at 2 967 angstroms are easily evaluated in absolute units, and the erythemal action, as well as the radiometric output, of the heterogenous ultraviolet radiation from various sources is readily correlated with this emission line as a standard
>
> From direct experiments it appears that a fifteen minute exposure to a flux density of 20 microwatts per square centimeter (or a total of 180 000 ergs) of homogeneous radiation of wavelength 2 967 angstroms does not produce an erythema on the average untanned skin though it may be somewhat too intense for a blond skin
>
> The Council has adopted 10 microwatts per square centimeter of homogeneous radiation of wavelength 2 967 angstroms as the erythemal unit (E U) of dosage intensity that is, 1 E U = 10 microwatts per square centimeter of radiation of wavelength 2 967 angstroms Twice this value (20 microwatts or 2 E U) is the minimum intensity for an exposure of fifteen minutes
>
> With 20 microwatts per square centimeter (2 E U) of homogeneous radiation of wavelength 2 967 angstroms as a standard of comparison in the accompanying table are given the erythematogenic equivalents

[37] Council on Physical Therapy A.M.A. Apparatus accepted 1942 pages 59 60

of the heterogeneous (the total integrated) ultraviolet radiation of wavelengths shorter than and including 3,132 angstroms required of various sources to produce a minimum perceptible erythema on the average untanned skin in fifteen minutes For an exposure of sixty minutes the minimum permissible values for sunlamps are one fourth as large That is to say, the total energy of unit intensity (20 micro watts per square centimeter) falling on a surface in fifteen minutes is the same as when one fourth the intensity (5 microwatts per square centimeter) is used and the surface irradiated sixty minutes, or four times as long. From this table it may be noticed that the lower the erythematogenic efficiency of the source, relative to the standard line at *2,967 angstroms* the *greater* must be the total ultraviolet intensity of wavelengths shorter than and including 3,132 angstroms in order to meet the Council s *requirements*

The table referred to in the preceding quotation follows

Erythematogenic Intensities of Heterogeneous Ultraviolet Radiation from Various Sources Equivalent to 20 Microwatts Per Square Centimeter of Homogeneous Radiation of Wavelength 2,967 Angstroms, Required to Produce a Minimum Perceptible Erythema

Source	Microwatts Per Square Centimeter
Homogeneous radiation of wavelength 2 967 angstroms only (mercury vapor arc)	20
Sun midday midsummer midlatitude sea level	91
Carbon arc blue flame cored carbon in reflector no window	48
Carbon arc glass window opaque to 2 800 angstroms and shorter (*estimated*)	90
Mercury arc Mazda type S-1 lamp, high temperature arc in parallel with C shaped tungsten filament in glass bulb	83
Mercury Arc Mazda type S 2 lamp similar to the S 1 lamp but smaller in glass bulb	93
Mercury arc quartz capillary type S-4 in glass bulb	80
Mercury arc type G-5 low temperature low voltage thermionic glow discharge glass bulb	108
Mercury arc high temperature high vapor pressure low voltage, quartz tube	58
Mercury arc low temperature low vapor pressure high voltage cold quartz Geissler tube discharge	36

From the foregoing table, one might erroneously conclude that the so called ' cold quartz" lamp, the source which requires the least intensity to produce a minimal perceptible erythema as determined by Coblentz should be the most effective source of radiation for ultraviolet therapy As we have already pointed out in our discussion of the production of erythema, Seitz has shown that the relative erythemogenic efficiency of radiation of wave length 2500 A U and 3000 A U will depend on the degree of erythema to be produced Evidently the Council on Physical Therapy recognizes the possibility of misinterpretation, and therefore states in the publication just referred to in discussing the "cold quartz lamp, that ' the erythematogenic efficiency of this type of lamp is high but that fact is not necessarily a criterion of its suitability for therapeutic purposes "

According to Coblentz [33] ' The erythemogenic efficiency of this type of lamp is high, but as shown in Chart 7 [of Coblentz article] practically all the erythemal effect is produced by the line at 2537 angstroms For this reason the question has arisen whether this type of ultraviolet radiation should be used for general body irradiation or whether its application should be con fined to special conditions '

A consideration of the spectral action curves given in the sum mary of biologic effects of ultraviolet radiation together with the discussion, will convince one of the limited field of usefulness of a source of this type Such a lamp is effective chiefly as a bac tericidal agent and then *only if the bacteria are accessible*

It is our opinion that the erythemal unit as defined by the Council in terms of energy units, is impractical from the view point of the clinician and may lead the uncritical reader to gross misinterpretation Furthermore the measurement in microwatts of the output of radiation in a selected spectral band requires apparatus not available to users of ultraviolet radiation for thera peutic purposes We believe that a simple determination of the exposure time required at various distances to produce a percept ible erythema 24 hours after exposure, will provide sufficient and

[33] Coblentz W W Sources of Ultraviolet and Infrared Radiation Used in Therapy J A M A 103 254 (July 28) 1934

adequate information on which to base a safe and effective technic of irradiation.

If a simple, relatively inexpensive device for measuring ultraviolet radiation of the desired therapeutic band were available, the operator would be enabled to administer a measured quantity of radiant energy, permitting duplication of treatment. Furthermore, such a meter would permit the determination of the amount of energy required to produce the various therapeutic effects.

Possibly the lack of agreement among clinical workers as to the effects produced by ultraviolet radiation is due to the fact that unmeasured quantities of radiation have been used. It is known that the irradiation of ergosterol with ultraviolet will activate it, but that after maximal vitamin D potency has been reached, further irradiation will destroy the vitamin D and produce some other product of a toxic nature. Whether or not the desired therapeutic effect is obtained may depend on the dosage administered. Bakwin and Bakwin[39] showed that in the irradiation with ultraviolet rays of infants with tetany there is an optimal range of dosage, above which and below which the rate of rise in the serum calcium is slowed.

But since a meter suitable for use by clinicians is not yet available, reliance must be on visual observance of the erythema and the technic of irradiation established accordingly.

According to the Council, an ultraviolet lamp is classified as a therapeutic unit if its intensity is such that a minimum perceptible erythema may be obtained in fifteen minutes at a distance of 24 inches from reflector edge to patient. A lamp which requires 15 minutes to produce an initial erythema would, however, require an inconveniently long exposure time to produce an erythema on that patient after he had received a series of exposures. A fully satisfactory lamp for ultraviolet therapy should be capable of producing a minimum perceptible erythema on the untanned skin of an average patient in 2 minutes at 40 inches, skin-tube distance. Such a lamp would not require inconveniently long exposure times for subsequent irradiations of the patient.

[39] Bakwin, H, Bakwin, R. M: The Dosage of Ultraviolet Radiation in Infants with Tetany J.A.M.A., 95 6 396 (Aug) 1930

For any particular lamp, the intensity of the radiation will be decreased as the distance between the lamp and the patient is increased Under the *Inverse Square Law*, page 189, the effect of increasing the irradiation distance upon the intensity of the radiation was fully discussed Furthermore, if the radiation is directed obliquely upon the patient, the intensity incident on the skin surface will be decreased The radiant energy impinging per unit area upon the patient will decrease as the angle between the beam and the surface decreases, the intensity being greatest when the angle is 90°, or when the radiation strikes the surface perpendicularly As has already been demonstrated, the intensity for an angle of $\Theta°$ deviation of the incident beam from the perpendicular, will be equal to the maximum intensity—which is the intensity when the beam is perpendicular to the surface—multiplied by the cosine of the angle $\Theta°$

The intensity of the radiation from a carbon arc lamp with given carbon electrodes, will depend upon the wattage consumed in the arc In order that a carbon arc emit radiation of constant intensity, constant arc voltage and current must be maintained As the arc burns, the distance between the electrodes increases with consequent change in arc wattage Even with an automatic mechanism to maintain approximately constant spacing between electrodes, there will be considerable fluctuation in the intensity of the emitted radiation

With the modern type of alternating current hot quartz mercury vapor arc, a reactance transformer is employed Approximately 3 minutes after starting the arc, the voltage over the arc reaches a stable value, assuring practically constant intensity of ultraviolet output

2 *Sensitivity of Patient* While the erythema resulting from exposure to ultraviolet radiation is by no means the most important biologic effect of ultraviolet, it serves as an indicator of skin tolerance Knowing the erythemal reaction of a patient will prevent over exposure and burning of the patient Furthermore, as has already been pointed out, the production of an erythema by the radiation from a lamp shows that the emitted radiation is capable of producing biologic effects

The time of exposure that is required to produce an erythema

on average untanned skin is a measure of the intensity of the radiation.

The exposure time required to produce an erythema will vary from patient to patient, and may, indeed, vary from day to day for an individual patient. Persons with fair skin and light hair are more sensitive than swarthy persons with dark hair. It has also been alleged that individuals with light colored eyes, regardless of color of hair, are more sensitive than those with dark colored eyes. The very young and the very old, according to Krusen, are also highly sensitive to ultraviolet, undoubtedly due to the thinness of their skin. Coblentz[40] observes that the untanned, moist skin requires an exposure of only about one-half to two-thirds as long as does dry skin for the production of a minimal perceptible erythema.

Another factor influencing the sensitivity of a patient is recent exposure to either artificial or natural ultraviolet radiation Such patients are less sensitive. On the other hand, certain foods may in certain individuals enhance the response of the patient.

Drugs, such as sulphanilamide, may render a patient hypersensitive Any substance which acts as a photosensitizer will bring about such an effect. Among such substances are eosin, quinine, methylene blue, and mercurochrome.

It is important, therefore, that the sensitivity of a patient be determined before a course of treatment is instituted. This can be done as follows:

A tolerance gauge such as that illustrated in Fig 89 is placed along the transverse processes of either side of the middorsal

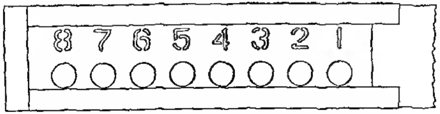


FIG 89 Tolerance guage for ultraviolet erythema test

[40] Coblentz, W W. Ultraviolet Radiation Useful for Therapeutic Purposes. Handbook of Physical Therapy. American Medical Association, Chicago, 1932.

spine. This area is less variable in skin response than most parts of the body. Such a gauge consists of a strip of material, opaque to ultraviolet radiation, in which there are a series of 8 to 10 holes, ½ to ¾ inch in diameter. The source of radiation to be used is placed at the treatment distance above the uncovered openings of the gauge. The lamp should be so positioned that the radiation will strike the exposed skin surfaces perpendicularly. Starting at one end, the apertures are successively closed at time-intervals of 15 seconds After 12 to 24 hours, the skin is examined, and the degree of erythema of each exposed area of skin noted. The degrees of erythema obtained will be those corresponding to exposures of 15 seconds, 30 seconds, 45 seconds, 60 seconds, etc. The erythemal response of the patient's skin to these exposures determines the time of exposure to produce a given erythemal reaction on that patient with the lamp tested, and at the distance employed in the test.

3. *Time of Exposure.* If one is assured of the absence of an abnormal sensitivity to ultraviolet radiation, the exposure time may be estimated for that patient on the basis of whether he is of light, medium, or dark complexion. To facilitate such a procedure, the time required by the lamps employed in the clinic to produce a minimal perceptible erythema on light, medium, and dark complexioned individuals at a standard irradiation distance should be determined A lamp should be standardized every 3 months, and the data recorded on a card attached to the lamp The data should be presented as follows:

LAMP NO ________ IRRADIATION DISTANCE________

Date	Average Time for Minimal Erythema Dose (M E D)		
	Light	Medium	Dark

4. *Degrees of Erythemal Dosage.* The degrees of erythemal dosage are:

a. Sub-erythemal dose (S.E.D.); no reddening of the skin.

b. Minimal erythemal dose (M.E.D.); a slight degree of reddening of skin without desquamation.

c. First degree erythemal dose (1 D); a slightly greater reaction associated with slight irritation followed by fine desquamation.

d. Second degree erythemal dose (2 D); a more marked reddening accompanied by itching and burning of the skin followed by free desquamation.

e. Third degree erythemal dose (3 D); a very severe reaction with swelling, edema, and the formation of blisters—a destructive reaction.

Beneficial therapeutic effects may be obtained without the production of a severe degree of erythema. Usually a minimal erythema dose (M.E.D.), or a sub-erythemal dose (S.E.D.), is administered when systemic effects are desired. However, the minimal erythemal dose (M.E.D.) is generally preferred.

The matter of over dosage of ultraviolet radiation is of great importance, especially in the treatment of children. In the case of an adult, one can be guided by the subjective reactions of the patient, but in the case of a child one must rely upon objective signs of over-dosage. The following are some of the indications of excessive dosage of ultraviolet radiation:

(1) Increased irritability
(2) Disturbed sleep
(3) Persistent loss of weight, or failure to gain weight, while under treatment
(4) Digestive disturbances and loss of appetite

B. *Procedure of Irradiation*

1. *General Body Irradiation.* Select an irradiation distance such that the entire body will be irradiated; usually a distance of 30 to 40 inches is employed. The distance chosen is one of individual preference. The lamp is so placed that the radiation is evenly distributed over the body surface. The shutters of the lamp are

kept closed until the lamp burner reaches a stable operating condition When stable operation has been reached 3 to 10 minutes after the arc has been established the shutters are opened, and the patient is irradiated for the length of time previously determined or estimated as sufficient to produce in his

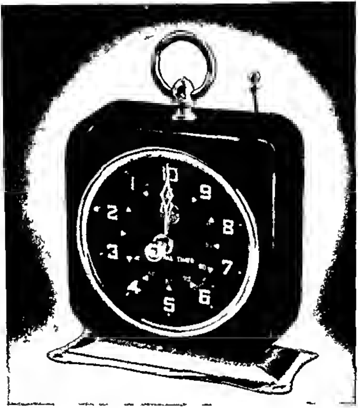


FIG 90 Mechanical interval timer

case the desired erythemal reaction The exposure time usually used is that which will administer a minimal erythemal dose (M E D) The exposure time is measured by means of an interval time clock Figs 90 and 91, which is set for the time of exposure The clock sounds an alarm at the expiration of the time interval The patient is irradiated in the nude, ventrally and dorsally, with

a towel over the genitalia. The towel may be removed by the patient during the actual period of irradiation. Care must be taken to protect the eyes from the ultraviolet radiation. This can be done by means of goggles, or by covering the eyes. The use of goggles is objectionable because of the resulting unsightly white

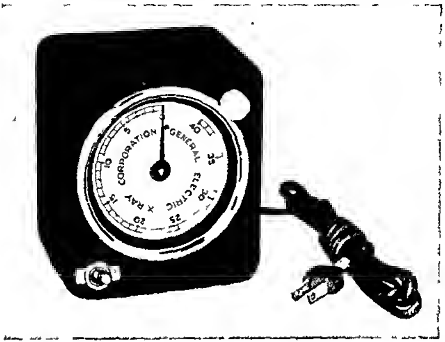


FIG 91 An electric interval timer.

rings about the patient's eyes. It will suffice in the case of adults for them to keep their eyes closed. In the case of non-cooperative patients and infants, the eyes can be protected by draping a towel from a coat-hanger to cover the neck of the patient, shielding the entire head from the radiation Fig 92.

Subsequent irradiations are at intervals of two to three days. The exposure time of subsequent treatments should not be increased until this time is insufficient to produce the desired erythema reaction. At that time the exposure time is usually increased to a multiple of the initial exposure time. For example, if 45 seconds were required initially to produce the desired

erythemal reaction, then when that exposure fails to elicit the response desired, the time of exposure is increased to 90 seconds, keeping, of course the irradiation distance the same

A series of treatments consists of 15 irradiations Following

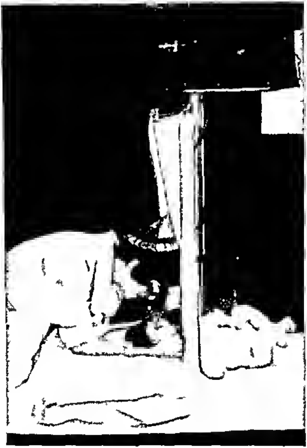


FIG 92 Method of shielding head from radiation by means of a towel suspended from a coat hanger

such a series treatment should be discontinued for at least two weeks before instituting a second series should a second series of treatments be necessary

2 *Regional Method* The regional or local application of the air cooled lamp is employed to produce a relatively intense local

reaction. The reaction may be achieved by decreasing irradiation distance to approximately 15 inches, or by increasing the time of exposure, or by both.

It has been found advantageous to secure second and third degree erythemal reactions in various skin diseases. The air-cooled lamp affords an excellent means for irradiating lesions that are quite extensive in area. Intense exposure can be directed to small areas by masking the surrounding skin.

Regional applications to large areas of the body for purposes of counter-irritation are readily made with the air-cooled lamp. Any degree of counter-irritation may be given accurately, basing dosage on results obtained in a tolerance test.

3. *Fractional Method.* The body is divided into four areas, namely: area No. 1, the chest; No. 2, the back; No. 3, the legs (ventrally); and No. 4, the legs (dorsally). Only one area is irradiated at each visit. The dosage of radiation is such as to produce an erythemal reaction which will last for 48 hours, followed by desquamation of the skin. Treatments are given two or three times weekly and so arranged that each area has a rest period of nine to ten days between treatments.

4. *Progressive Method.* The Progressive Technic was originated by Dr. Rollier at Leysin, Switzerland.

In his practice he found that some of the cases suffering from pulmonary tuberculosis reacted unfavorably when their entire bodies were exposed to a source of ultraviolet radiation In view of this fact, Dr. Rollier developed a method of irradiation whereby he gradually increased the tolerance of these patients to a degree that would permit of general exposures without the undesirable reactions.

The progressive technic involves the division of the body into five parts, or sections: section No. 1, including the feet and ankles; section No. 2, the legs; section No. 3, the thighs; section No. 4, the abdomen; and section No. 5, the thorax. The initial dosage is determined by the susceptibility of the patient. The section or sections receiving irradiation are exposed both ventrally and dorsally. In the first treatment, section No. 1 receives one unit of dosage. In the second treatment, section No. 2 receives

one unit and section No. 1 receives two units. In the third treatment, section No. 3 receives one unit, section No. 2 two units, and section No. 1 three units This progression continues until finally section No. 5 receives one unit, section No. 4 two units, section No 3 three units, section No. 2 four units, and section No. 1 five units. At the next treatment, sections 1 and 2 will receive five units; section 3, four units; section 4, three units; and section 5, two units. In this manner, irradiation to the various

Visits	Feet	Legs	Thighs	Abdomen	Thorax
1st	1 unit				
2nd	2 units	1 unit			
3rd	3 units	2 units	1 unit		
4th	4 units	3 units	2 units	1 unit	
5th	5 units	4 units	3 units	2 units	1 unit
6th	← 5 units Combined →		4 units	3 units	2 units
7th	← 5 units Combined →			4 units	3 units
8th	← 5 units Combined →				4 units
9th	← 5 units Combined →				

FIG 93 Progressive method of ultraviolet irradiation (Rollier)

sections is progressively increased until all sections, or the entire body, is receiving five units at each treatment. When any section receives the maximum number of units, namely five, it is combined with preceding sections and these sections are irradiated as one Eventually all sections will be combined, and the entire body will be irradiated as a whole As shown in Fig 93, this occurs on the ninth treatment However, it may not be advisable to increase irradiation this rapidly. The technic must be modified as indicated by the patient's reaction.

It was found by Dr Rollier that many of his patients who reacted unfavorably to general irradiation, were successfully treated by gradually building up the tolerance by means of the *Progressive Method*. Since then, this method has been adopted by various sanatoriums and clinics in the treatment of pulmonary tuberculosis.

5. *Special Applications*

a. *Localized Application.* When intense irradiation of small, localized lesions is desired, the irradiation distance should be greatly decreased in order that a high intensity of radiation be obtained. However, the long wavelength infrared radiation, emitted by the source, prevents the desired close application because of the excessive heating of the superficial tissues. By enclosing the quartz burner within a water-cooled jacket and filtering the radiation through a double window of quartz, between which water is circulated, a source of radiation is provided which permits close application. The water filter absorbs the undesired long wavelength infrared rays while passing readily the shorter, penetrating infrared, the visible, and the ultraviolet. Quartz applicators of various sizes and shapes may be used with the lamp for cavity irradiation, and for applying pressure during irradiation. Such a lamp is known as a water-cooled lamp. It is claimed that penetration of the ultraviolet radiation is increased by subjecting the irradiated tissue to pressure, resulting in a partial debematization; but inasmuch as it is the corneum, or horny layer, that absorbs the ultraviolet principally, it is questionable in our opinion that pressure and resultant dehematization of deeper layers of tissue will appreciably increase penetration.

b. *Use of Coal Tar as Sensitizing Agent.* In the treatment of psoriasis it has been recommended by Goeckerman[41, 42] that coal tar be employed as a sensitizer to ultraviolet radiation. The ointment consists of 2 grams each of crude coal tar and pulverized zinc oxide, mixed with 2 ounces each of corn starch and petrolatum It is applied to lesions for twenty-four hours, and then lightly removed with olive oil, leaving a thin film covering the lesions. Irradiation with ultraviolet from a hot quartz mercury vapor arc is administered at a distance of 30 inches for one minute, the time being increased daily by increments of one

[41] Goeckerman, W. H.: The Treatment of Psoriasis Northwest Medicine 24.229-231 (May) 1925.

[42] Goeckerman, W. H.: Tar and Ultraviolet Radiation in the Treatment of Psoriasis. Brit. J. Physical Med 7:215 (March) 1933.

minute for 3 or 4 days After each irradiation, the patient bathes with soap and water or with oatmeal and soda After bathing, another application of ointment is made which is permitted to remain until the next irradiation If a reaction is not obtained, the irradiation time is increased or the distance is decreased until the desired reaction is secured It is stated that all patches of psoriasis should be capable of being removed in three to four weeks Marked erythemal reaction is to be avoided, but tanning should be produced

General irradiation of the entire body, twice weekly, is said to be of distinct value as an adjuvant to the local treatment of individual lesions

According to O Leary[41] approximately 12 per cent of psoriatic patients have arthritis of one type or another, either chronic infectious senescent, or psoriatic arthritis In this latter group, he found the treatment to be successful, not only in causing dis appearance of the cutaneous lesions but also in relieving joint pains

O Leary s treatment consists of the use of coal tar ointment (2 to 4 per cent) ultraviolet radiation, oatmeal baths, and auto hemotherapy On the first day in the hospital all the patches of psoriasis are covered thickly with the ointment, which is left on overnight The following morning it is removed with a light weight mineral oil but care should be taken to leave a thin film of the oil on the skin The reason for this is not known but experience has shown that it is essential At the first treatment radiation is applied for one minute at a 30 inch distance after dividing the skin surface into six areas The time of exposure is increased and the distance decreased each day in order to maintain the skin in a state of mild erythema It is advisable to keep the reaction from the ultraviolet radiation below the point of blistering although in certain cases this is difficult to do when one is endeavoring to produce erythema in a large, indurated plaque

After irradiation the patient spends half an hour to two hours in an oatmeal bath or in a tub of water kept at approximately 95° F This procedure loosens the scales and allows the patient to remove

[41] O Leary Paul A A Method of Treating Psoriasis Canad M A J 48 34 1943

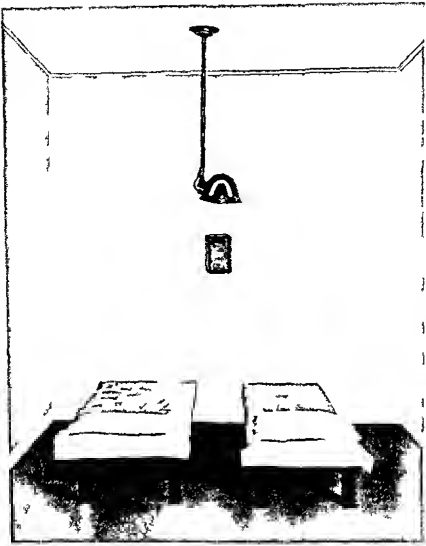


Fig 95 A single ultraviolet lamp installed for simultaneous irradiation of two patients

ously Such an installation however is not economical for the irradiation of a few patients Considerable electrical power is required of the order of 5 000 watts and an efficient ventilating means must be provided to carry away the fumes of the lamp

With such precautions, the installation can be used satisfactorily for the irradiation of large numbers.

The quartz mercury vapor arc lamp can be used singly or in multiples, depending upon the number of patients to be irradiated simultaneously. In Fig 95 is shown the use of a single lamp for the irradiation of two patients at the same time. Similarly, an installation of four lamps can be arranged to irradiate eight patients simultaneously. A definite advantage of this type of solarium is the possibility of using any number of the lamps depending upon the number of patients it is desired to irradiate.

An ingenious method for group irradiation has been devised that is particularly adapted to the prophylactic irradiation of students, miners, and others whose working conditions prevent adequate exposure to solar ultraviolet radiation. In Fig 96 is shown such an installation, designed especially for the irradiation of miners. After their shower, the miners walk a distance of 16 feet between guard rails, one of which supports a flexible belt which moves at the rate of 16 feet per minute. The belt is equipped with suitable markers at intervals of 4 feet. Each man takes hold of the belt at one of the marked points, and walks at the speed determined by the belt travel.

The lamps are permanently mounted, and spaced alternately at 4-foot intervals on both sides of the lane travelled by the men The reflectors are adjusted to direct the radiation horizontally The result is a fairly uniform distribution of radiation throughout the 16-foot length.

For reflectors of different distribution, the spacing of lamps, their mounting height above the floor, and the distance between the lamps and the center of the lane would, of course, be different

In the installation just described, a subject during his travel through the lane would be subjected to a total quantity of radiation comparable to that administered to produce a minimal erythema. This arrangement for group irradiation will irradiate four subjects per minute, or 240 per hour.

C. *Contra-indications.* Ultraviolet radiation is a useful therapeutic agent, but its use is contraindicated in certain conditions. Its effective use must be guided by a thorough appreciation of its

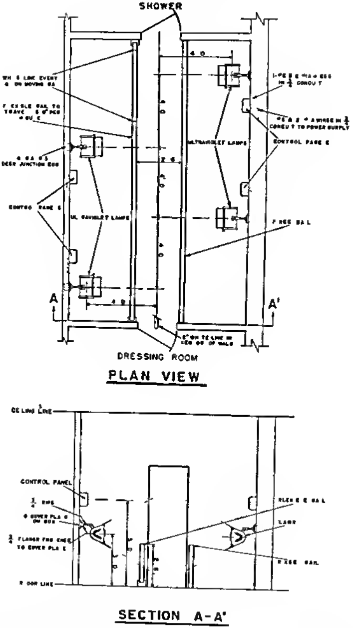


FIG 96 Ultraviolet installation for the prophylactic irradiation of large groups This particular installation is capable of irradiating over 200 individuals per hour (Bunker Hill and Sullivan Mining Company Kellogg Idaho)

possible untoward effects. According to Krusen,[44] the following conditions are contraindications to the use of ultraviolet radiation:

1. Progressive exudative forms of pulmonary tuberculosis involving adrenal glands. Certain types of tuberculous tracheobronchial adenitis in which there may be a febrile reaction, loss of weight and fall in blood pressure following irradiation.
2. Hyperthyroidism
3. Diabetes
4. Highly nervous individuals
5. Advanced cachexia or inanition
6. Aged persons having acute nephritis or myocarditis
7. Acute forms of generalized dermatitis
8. Photogenic diseases of the skin such as pellagra, lupus erythematosis, hydroae-aestivale and xeroderma pigmentosum.
9. Hyperglycemia
10. Severe chronic nephritis

Of particular importance is the photosensitizing effect of the sulpha drugs, as already pointed out. Such drugs may give rise to severe reactions Before irradiating a patient, ascertain what drugs are being administered, or have recently been administered.

D. *Prescription.* When referring a patient for ultraviolet therapy, the referring physician should provide the technician with a prescription outlining the treatment to be administered The following information and directions should be provided:

1. *Source.* Mercury quartz, or carbon arc with designation of type of carbon electrodes to be used
2. *Irradiation Distance.* 30 inches; 36 inches; or 40 inches
3. *Erythemal Dose.* Suberythemal (S E.D); minimal erythemal (M E D); first degree (1 D.); second degree (2 D.); or third degree (3 D.).
4. *Technic of Irradiation.* General body irradiation; regional; fractional; or progressive.
5. *Frequency of Irradiation* Times per week.
6. *Total number of Irradiations.* Specify.
7. *Rest Period Between Series of Irradiations.* Specify.
8. *Special Instructions.* Use of coal tar nintment, etc.

[44] Krusen, F H.· Physical Medicine. W. B. Saunders Co, Philadelphia, 1941.

EXPERIMENT 1

The Transmission of Ultraviolet Through Window Glass

Object

To demonstrate that ordinary window glass is opaque to radiation which produces an erythema

Theory

Ordinary window glass filters out radiation shorter than 3100 A U , page 258 The radiation which produces an erythema and pigmentation is of shorter wavelength than this, page 270 Therefore, radiation passing through window glass will be incapable of producing an erythema and the various other biologic effects produced by radiation of wavelength shorter than 3100 A U , page 284

Apparatus

1 A source of ultraviolet light such as a hot quartz mercury vapor arc lamp
2 A 4 by 4 inch piece of ordinary window glass

Procedure

1 Place the window glass on the flexor surface of the forearm and expose it to a source of ultraviolet radiation Place the lamp at 30 inches, a distance ordinarily used in clinical practice Let the exposure time be that which will produce an M E D on the uncovered skin This will vary from 30 seconds to 1 minute according to the efficiency of the lamp and the sensitivity of the patient
2 Expose the unprotected flexor surface of the other forearm to the ultraviolet radiation, using the same irradiation distance and the same exposure time

Observations

Fill in the information called for in the following table The latent period is the time elapsing between irradiation and the ap

pearance of the erythema, which may vary from 6 to 24 hours, depending upon the spectral distribution of the radiation employed in the test. The spectral distribution of the radiation from a hot quartz mercury vapor arc is such that the latent period for this type of lamp is approximately 6 to 8 hours

	Glass Filtered Radiation	Unfiltered Radiation
Type of Lamp		
Arc Watts		
Time of Exposure		
Skin Burner Distance		
Immediate Effect		
Latent Period		
Degree of Erythema		
Duration of Erythema		
Effect Succeeding Ery thema		

Conclusion:

Ordinary window glass is opaque to ultraviolet radiation which produces an erythema

Discussion:

In the experiment it was demonstrated that window glass does not transmit ultraviolet radiation of those wavelengths capable of producing an erythema Such wavelengths are less than 3100 A U , Fig 85, page 272. From Fig 87, page 282, it is seen that the other establisbed effects of ultraviolet also require radiation of wavelength less than 3200 A U. Therefore, radiation filtered by window glass will be incapable of producing any of the established biologic effects of ultraviolet radiation

EXPERIMENT 2

Determination of the Erythema Time at Various Distances From an Ultraviolet Lamp

Object:

To determine the exposure time required to secure the same degree of erythema at various irradiation distances.

Theory:

The intensity of radiation from a point source varies inversely as the square of the distance Therefore, to secure the same reaction if the distance between such a source and the subject is increased, it will be necessary to increase the time of exposure as the square of the ratio of the distances—that is, if the distance is doubled, the time of exposure must be increased four-fold

In the case of a lamp equipped with a reflector and having a source of radiation which is not a point source, this relationship will not of course strictly apply However, an approximate estimate of the exposure time at various distances can be obtained by applying the inverse square law. In this experiment the exposure time required for a given erythemal reaction at different irradiation distances will be experimentally determined Assuming the experimentally determined erythemal time for 30 inches, the erythemal time for other distances will then be computed on the basis of the inverse square law The per cent error due to the use of the inverse square law in computing exposure time will then be computed

Apparatus:

1. A source of ultraviolet radiation
2. A skin tolerance gauge

Procedure:

1. Place a tolerance gauge on the area to be irradiated, shielding all other exposed skin surfaces from the radiation by means of a sheet. Close all the apertures Position the lamp

for an irradiation distance of 30 inches. Close the shutters and turn on the lamp After the lamp has reached stable operation, open the shutters. Then open aperture No. 8 of tolerance gauge After 15 seconds open aperture No. 7, leaving aperture No 8 open. At the end of another 15 seconds open No 6 Continue this procedure until aperture No. 1 has been exposed for 15 seconds The shutters of the lamp are then closed. A series of exposures will have been obtained, starting at 15 seconds and increasing by increments of 15 seconds. Aperture No 1 corresponds to an exposure of 15 seconds, No 2 to 30 seconds, etc, to No. 8, which corresponds to an exposure of 2 minutes. When the resulting erythemas have reached their maximum intensity, sometime during the 24 hours following irradiation, select the exposure time that gave a minimal erythemal dose (M.E.D.).

2. Then irradiate in a similar manner another skin area of similar sensitivity, using an irradiation distance of 40 inches.
3. Repeat for an irradiation distance of 50 inches.
4. Record data obtained in a table similar to that in the next paragraph and perform the indicated computations.

Observations and Computations:

Distance	Exposure Time for M E D		
	Experimental Time	Computed Time, Assuming Inverse Square Law Applies*	Per Cent Error
30 inches	0 5 min	0 5 min (Assumed)	0
40	1 0	0 9	10
50	1 75	1.4	20

* $\left(\frac{d}{\;}\right)^2$ in which d is the new irradiation distance

EXPERIMENT 3

Variation in Erythemal Response of Different Subjects

Object

To demonstrate that individuals differ in their erythemal response to ultraviolet radiation

Theory

It has been observed that differences in skin color cause variations in erythemal response to radiation It is generally agreed that blondes react more markedly than do brunettes for a given exposure furthermore that blondes tend to burn without marked pigmentation while brunettes rarely burn but respond with deep pigmentation

As pointed out in the text page 276 the thickness of the corium will have an influence on the response of an individual to ultraviolet radiation the individual with a thick horny layer being less sensitive than one with a thin corium Also sensitivity may be altered by drugs and foods In the administration of ultraviolet radiation consideration must be taken of all these factors In this experiment tests will be conducted to determine the influence of skin color alone on sensitivity Should however data be obtained which deviate markedly from the general rule that blondes are more sensitive than brunettes an attempt should be made to ascertain the reason for such deviation Observe the color of the eyes of the subject as well as the color of his skin Ascertain whether the subject has been sensitized to radiation by certain drugs or by certain foods Ascertain his age and whether the subject has a thin sensitive skin Careful performance of this test and thorough analysis of the results will provide one with practical information on which to base exposure time for ultraviolet irradiation

Apparatus

1 A source of ultraviolet radiation
2 A tolerance gauge

Procedure:

1. Select an irradiation distance commonly used in clinical practice, for example, 30 inches.
2. Expose the trunk of each subject to ultraviolet radiation, using a tolerance gauge such as that described in Experiment 2. Make exposure increment 15 seconds. Observe the development of erythema during the 24 hours following irradiation. When the erythema reaction has reached its maximum, ascertain by inspection the exposure time required to give a *minimal erythemal dose* (M.E D.) in the case of each subject Three subjects should be used: a brunette, a blonde, and one of medium coloring

Observations:

Record your observations in the following table.

Subject	Distance Used	Exposure Time for M E D
Blonde		
Medium		
Brunette		

PART D HIGH FREQUENCY CURRENTS

SECTION ONE ELEMENTARY ALTERNATING CURRENT CIRCUIT THEORY

SECTION TWO ALTERNATING CURRENTS OF HIGH FREQUENCY

SECTION THREE TECHNIC OF LOCAL APPLICATION

(For contents of Section Four see page 558 for Section Five see page 609 for Section Six see page 655)

SECTION ONE ELEMENTARY ALTERNATING CURRENT CIRCUIT THEORY

The high frequency electric currents used in medicine and surgery are alternating currents having frequencies greater than those frequencies which elicit a neuromuscular response The purpose of their employment is to generate heat within tissues When the application is such that visible destruction of tissue results, the application is surgical Such application as produces no visible destruction has been considered medical. However, the application should be considered medical only when the heat generated in the tissues promotes their physiological well-being Between the temperatures which are not destructive from either a physiological or morphological viewpoint and those which are visibly destructive, there is a range of temperatures which are definitely deleterious to the proper functioning of tissues, although even after prolonged maintenance no visible destruction may be observable. Such functional impairment of tissue will be manifested by an aggravation of pain, an increase in edema, and the appearance of various other symptoms of over-heating Obviously it is important to consider the technic to be employed in the treatment of various conditions and to adapt the technic as regards the method of application, the intensity and duration of treatment, and the frequency with which treatments are to be administered, so that such untoward effects will be obviated In order that one may intelligently administer high frequency currents, individualizing each treatment technic to the pathological condition present, a knowledge of the fundamental physical laws governing the generation of alternating currents and the various factors influencing the flow of such currents through various circuits, and particularly through electrolytes, is necessary Therefore, this section will be devoted to a consideration of such fundamental principles of alternating current phenomena as in our opinion will impart to the student the fundamental laws and concepts on which the technic of shortwave diathermy should be based Before considering alternating currents of high frequency, a brief consideration of alter-

nating current circuit theory in general will be undertaken.

GENERATION OF A SINUSOIDAL ALTERNATING CURRENT The generation of electricity can be demonstrated by thrusting a permanent magnet into a coil, the terminals of which are connected to a voltmeter of suitable range with zero point at the center of the scale. As the magnet is thrust into the coil, the meter deflects in one direction; and when it is withdrawn, the meter deflects in the opposite direction It will be observed that the amplitude of the deflection depends upon the speed with which the magnet is thrust into the coil or withdrawn from it, the greater the speed, the greater will be the deflection When the magnet is kept stationary, no deflection occurs Obviously, the generation of voltage is associated with the motion of the magnet.

Lines of magnetic force may be considered leaving the north pole of the magnet, spreading out into space, and returning at the south pole The distribution of these lines of magnetic force can be visualized by placing a piece of paper over a permanent magnet, sprinkling iron filings over the paper, and tapping the paper gently The iron filings will arrange themselves along the lines of magnetic force If blueprint paper is used, exposed to light for the necessary length of time after the iron filings have arranged themselves, and then developed, a permanent record of the lines of magnetic force of a magnet can be obtained.

When the magnet is thrust into the coil, these magnetic lines of force cut the turns of the coil, inducing therein an electromotive force, which produces a deflection of the voltmeter On withdrawing the magnet, the lines will again cut the turns of the coil, inducing an electromotive but of opposite polarity, since now the lines of force are cutting the turns of the coil in the opposite direction We arrive at the conclusion that an electromotive force is generated whenever a conductor is cut by lines of magnetic force —the rate at which the cutting takes place determining the magnitude of the voltage, and the direction of cutting the direction in which the resulting current will flow It has been determined that an electromotive force of 1 volt will be induced if a conductor cuts magnetic lines at the rate of 100,000,000 lines per second

The same voltage obviously would be induced whichever is kept stationary while the other is moved—the coil or the magnet

The phenomena just described are applied in the design and construction of generators of electric current Fig 97 represents a simple type of generator. As the coil rotates in the magnetic field which exists between the two poles of the generator, an electromotive force is induced in the coil, the voltage at any instant being the rate at which the coil is cutting lines of magnetic force

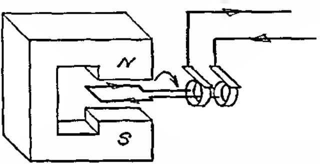


Fig 97 Simple alternating current generator With the place of the coil at right angles to the magnetic flux as indicated in the figure, the induced emf is zero But as the coil continues to rotate in the direction indicated, an emf will be induced, its instantaneous value gradually increasing as the angular displacement of the plane of the coil increases, reaching a maximum when the angular displacement is 90° As the displacement increases from 90° to 180°, the instantaneous value decreases, becoming zero when the angular displacement becomes 180° During this time the current will flow in the direction indicated by the arrow heads A similar variation in the magnitude of the induced emf will occur during the second half revolution, but the direction of the resulting current flow will be reversed One complete revolution will produce one complete cycle of emf

at that instant When the coil is in the position shown in Fig 97, the voltage is obviously zero, since at this instant the motion of the sides of the coil is parallel to the lines of magnetic force and consequently no lines are being cut, and hence no voltage is being induced When at right angles to this position, the coil is cutting lines at the greatest rate, and the voltage being induced at this instant is a maximum When the coil has rotated 180°, or π radians,* from this position, the coil will again be cutting lines at

* *Radian Measurement of Angles* A unit of angular measurement widely

the maximum rate and the induced electromotive force will again be a maximum The polarity of the induced voltage, however, will

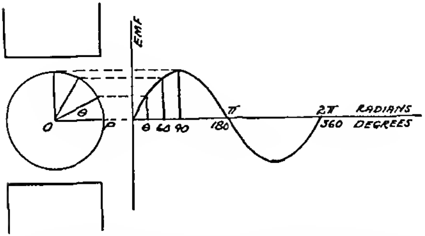


FIG 98 Schematic diagram showing relation between position of rotating coil and induced emf The instantaneous value of the induced emf (e) equals the sine of the angle of displacement ($\sin \theta$) times the maximum value of the induced emf (E_M) or in symbols

$$e = E_M \sin \theta$$

The voltage follows a definite mathematical law the *sine law* and hence is known as a *sinusoidal* voltage

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employed is the *radian* The radian is the central angle of a circle which subtends an arc of that circle equal in length to the radius of the circle Therefore the number of radians in an angle can be found by describing a circle of any convenient radius about the vertex of the angle as a center measuring the length of the arc intercepted by the sides of the angle and dividing this length by the radius of the circle In a circle therefore the number of radians equals the circumference divided by the radius or

$$\frac{2\pi \times \text{radius}}{\text{radius}} \quad \text{or} \quad 2\pi \text{ radians}$$

Therefore

$$1 \text{ radian} = \frac{360}{2\pi} \text{ degrees}$$

$$1 \text{ radian} = 57.3^\circ$$

be reversed For intermediate positions of the coil between that for zero electromotive force and that for maximum electromotive force, only a certain component of the tangential motion of the coil will be at right angles to the magnetic field and hence effective in generating a voltage in the coil. From Fig. 98 it can be readily deduced that this component is proportional to the sine of the angle of displacement measured from P or the zero position. If B equals the number of magnetic lines per square centimeter, and V the tangential velocity of the side of the coil in centimeters per second, the number of lines cut per second by each cm of the side of the coil is equal to B $\times$ V $\times$ sine θ, θ being the angle of displacement. The product (V sine θ) represents the component of V that is perpendicular to the magnetic field and hence effective in generating an electromotive force. The maximum rate of cutting occurs when θ is 90° or $\pi/2$ radians, or when the tangential velocity is perpendicular to the field. At this instant the rate of cutting equals BV. If the corresponding induced emf is E_M, then the emf induced at any instant is

$$e = E_M \sin \theta$$

The voltage induced in the coil has been shown to be alternating and to follow a definite mathematical law—the *Sine Law*. Hence the induced voltage is designated a sinusoidal alternating voltage. The quantitative relationships given in the succeeding paragraphs are based on the assumption that the alternating currents and voltages dealt with follow the sine law and are therefore true sinusoidal variations.

By the use of a commutator instead of slip rings, as the current collectors of an alternating current generator are called, the generated voltage can be rectified. The sine wave of voltage generated by the rotation of a coil in a magnetic field will be delivered to the brushes on the commutator as a pulsating unidirectional electromotive force. If the number of coils and correspondingly the number of commutator bars are increased, the voltage delivered to the brushes and load will more closely approach a constant value, the ripple, as the variation from a constant value is termed, decreasing as the number of coils and commutator bars increases.

Frequency. Each revolution of the coil will generate a complete

cycle If 60 complete cycles of current variation are to be delivered per second, the coil would have to rotate at the speed of 60 revolutions per second, or 3600 revolutions per minute For a four pole generator, the speed would be 1800 revolutions per minute To obtain higher frequencies corresponding increase must be made in the angular speed of the coil The frequency of an alternating current is the number of times the current passes through a complete cycle of forward and backward motion during a unit of time If the unit of time is the second, the frequency is expressed in cycles per second

Effective Value of a Sinusoidal Alternating Current or Voltage The instantaneous value of a sinusoidal alternating current varies continuously throughout the cycle The average value over a complete cycle is zero Therefore, some other value of the current wave must be used as a measure of the intensity of the current It has been found convenient for the purpose of measurement and computation to choose as a measure of the intensity of the alternating current that instantaneous value of the current which is equivalent in heating value to a continuous current of the same magnitude The symbol for the effective value, as this value is termed, is I, whereas that for the instantaneous value is i, and that for the maximum or peak value of the alternating current wave is I_M The effective value can be shown to be equal to 70 7 per cent of the maximum value In symbols

$$I = \frac{\sqrt{2}}{2} I_M = 0\ 707\ I_M$$

The effective value of an alternating voltage is also equal to 70 7 per cent of the maximum value of the voltage wave In symbols

$$E = \frac{\sqrt{2}}{2} E_M = 0\ 707\ E_M{}^*$$

* *Effective Value* In Fig 99 Curve i represents a sinusoidal alternating current flowing through a resistance of R ohms The product of the instantaneous current squared and the resistance (i^2 R) will give the instantaneous power Computing the instantaneous power over the cycle and plotting these values, Curve p, which represents power absorption throughout the cycle, is

Average Value of a Sinusoidal Alternating Current or Voltage As already pointed out, the average value of a complete cycle is zero The average value of a half cycle can be shown to be 63 6 per cent of the maximum value This average value is used at times In symbols

$$I_{AV} = 0\ 636\ I_M \text{ and } E_{AV} = 0\ 636\ E_M$$

OHM'S LAW FOR THE ALTERNATING CURRENT CIRCUIT Let us consider a coil, having an ohmic resistance of 20 ohms, on which a

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obtained Note that during the negative phase of the current cycle power is still absorbed in the resistance From a mathematical viewpoint the instantaneous power during this phase should be positive since the square of the negative current will give a product with a positive algebraic sign From a physical viewpoint power should be dissipated in the resistance during the

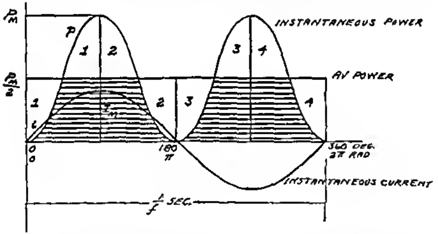

FIG 99 Curve showing instantaneous value of power absorbed by a non inductive resistance throughout a complete cycle of sinusoidal alternating current flowing through the resistance The average power is $P_M/2$ P_M being maximum or peak value of the power curve The instantaneous values of the power curve are obtained by squaring the instantaneous values of the current and multiplying by the resistance i e

$$p = i^2R$$

The power absorption is that which would take place if a direct current of value I were flowing This value is called the effective value of the alternating current and is equal to 70 7 per cent of the maximum or peak value of the current.

direct current voltage of 100 volts is impressed The current that will flow is obviously 100 volts divided by 20 ohms or 5 amperes If we now apply an alternating current having an effective voltage of 100 volts, the resulting effective current will not be 5 amperes but a value that may be much less than 5 amperes It is evident that the coil exerts a greater opposition to the flow of an alternating current than to a direct current Since there has been no change in the number of turns of the coil, the diameter of the coil, nor in the size or material of the conductor, the increased opposition of the coil to the flow of an alternating current must be due to the alternating character of the impressed voltage

Let us now consider a direct current voltage impressed on a circuit containing a condenser, which consists of parallel conductive surfaces separated by an insulator Current will flow for a very short period of time or until the condenser has been fully charged When this point has been reached, no further flow will

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negative phase of the current as well as during the positive phase, for power is dissipated whenever a current flows through a resistance irrespective of the direction in which the current flows through the resistance, assuming of course that the resistance remains constant in value regardless of the direction of current flow This is the type of non inductive resistance assumed in this discussion of the effective value of an alternating current

The product of a sine wave by another sine wave will be a sine wave Each half of a sine wave is symmetrical about the ordinates at 90° and 270° which represent the maximum amplitude of the wave, positive and negative respectively Therefore, if a horizontal line is drawn bisecting the maximum value of the power curve, those areas included under the power curve and above this line will fill perfectly those remaining spaces under the horizontal line and above the horizontal axis which are not included under the power curve The total electrical energy absorbed by the resistance during one cycle is equal to the average power absorbed during the cycle multiplied by the time required for the current to pass through a complete cycle of values The average power is equal to the area in terms of watts times seconds under the power curve over one cycle divided by the time of one cycle, or is equal to the altitude of a rectangle having as a base the time of 1 cycle and an area equal to the area under the power curve for one cycle Obviously from Fig 99 and the foregoing discussion, the area in watt second units under the power curve for 1 cycle is equal to that in watt seconds of a rectangle having an altitude equal to ½ the maximum or peak value of the power curve and a base equal to the time of one cycle, or $1/f$ seconds f being the frequency of the current in cycles per second The energy absorbed per cycle is then

occur unless the voltage is raised Should the impressed voltage be increased, current will again flow until the condenser is charged to the potential of the impressed voltage and then again cease to flow. Obviously direct current will not flow continuously through a condenser Let us now impress an alternating electromotive force on the condenser circuit, which has an effective voltage equal to the voltage of the direct current previously impressed on the condenser Whereas no steady current flowed when a direct current voltage was impressed, a steady alternating current will be found to flow when the alternating voltage is impressed A condenser, therefore, *permits* the flow of a *steady alternating current* but does not permit the flow of a steady direct current As in the case of the coil, the change in opposition to the flow of current is due to the alternating character of the impressed voltage

The total opposition exerted by a circuit to the flow of an alternating current is called the *impedance* of the circuit The magnitude of the impedance will depend on the electrical characteristics of the circuit, in some cases being equal to the resistance to the flow of a direct current but usually greater than the direct current resistance The frequency of the impressed alternating voltage will affect the value of the impedance, increasing it in certain types

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$$\frac{P_M}{2}\,\frac{1}{f} = \frac{I_M^2 R}{2}\,\frac{1}{f}$$

From the definition of the effective value of an alternating current,

$$I_{eff}^2 R\,\frac{1}{f} = \frac{I_M^2 R}{2}\,\frac{1}{f}$$

whence

$$I_{eff} = \frac{I_M}{\sqrt{2}} = \frac{\sqrt{2}}{2} I_M = 0.707\ I_M$$

In a similar manner,

$$E_{eff} = \frac{\sqrt{2}}{2} E_M = 0.707\ E_M$$

The effective values of an alternating current and voltage may also be defined as those values of the voltage and current which when multiplied together give the average power being absorbed in the non inductive resistance upon which the voltage wave is considered impressed

of circuits and decreasing it in others Hence some modification in Ohm's Law as applied to direct current circuits must be made before this law can be applied to an alternating current circuit

Before such modification can be made, however, a careful anal

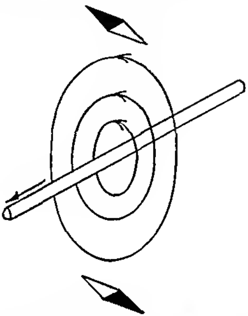

FIG 100 Schematic representation of the magnetic field about a straight conductor carrying a current. The closed arrow head indicates the direction of current flow in the conductor and the open arrow heads the direction of the magnetic field—its direction being the direction in which a unit north magnetic pole would move if placed in the field It is also the direction in which the north seeking pole of a compass needle would point if placed in the field as is indicated by the two compass needles one above and one below the conductor which have their north seeking halves shaded.

ysis must be made of what electrical phenomena take place in various types of circuits on impressing an alternating voltage In the following paragraphs the flow of alternating current through different types of basic circuit elements such as condensers coils and pure resistances will be considered, and also the influence of frequency on the opposition these basic circuit elements oppose to the flow of alternating current

Inductance and Inductive Reactance When an electric current

flows through a conductor, a magnetic field is set up around that conductor. The existence of the magnetic field can be demonstrated by means of a magnetic compass. In Fig. 100 an electric current is flowing in the conductor in the direction indicated by the arrow. If a compass is placed over the conductor, its north-seeking pole will be deflected as indicated. If placed under the conductor, the compass needle will be deflected in the opposite direction. From this simple experiment it can be deduced that closed magnetic lines surround the conductor. If a hypothetical magnetic pole of unit strength (a unit magnetic pole) were placed in this field, it would rotate about the conductor in a definite direction. If the current is reversed, the direction of rotation of the unit magnetic pole would also reverse.

The existence of the lines of magnetic force about a conductor carrying a current can also be readily demonstrated by sprinkling iron filings on a cardboard through which the conductor passes at right angles. On tapping the cardboard, the iron filings will arrange themselves along the lines of magnetic force. By using blue-print paper a permanent record of the magnetic field can be obtained. Sufficient current must be employed to obtain best results in this experiment.

The direction of these lines of magnetic force, *i.e.* the direction in which a unit positive or north magnetic pole would move, can be determined by considering your right hand placed around the conductor with fingers closed and thumb extended in the direction of current flow. The fingers will then indicate the direction of the lines of magnetic force. Another rule for determining the direction of the magnetic field is to consider a right-handed screw rotated in such a direction that it would advance in the direction of the current flow. The direction of rotation of the screw will then be the direction of the magnetic field about the conductor.

If a conductor is wound into a coil, the magnetic field set up by a current flowing through it will be such that a north pole is produced at one end of the coil and a south pole at the other. The end at which the north pole is established can be ascertained by placing your right hand around the coil with the fingers pointing in the direction in which the current is flowing in the turns mak-

ing up the coil and extending the thumb along the coil The direc tion in which the thumb extends will indicate the end of the coil at which the north pole is established The position of the north pole can also be determined by imagining a right handed screw placed in the end of the coil and considering it being rotated in the direction in which the current is flowing through the turns of the coil The direction of travel of the screw will then indicate the direction of the magnetic field The north pole is therefore at that end of the coil towards which the rotating screw advances

In our study of direct currents we have seen that when a steady current is flowing through an electric circuit, a certain definite voltage is required to maintain the flow of this current The re quired electrical pressure depends upon the resistance of the cir cuit and upon the work to be done by the current So far, we have been concerned only with steady currents Nothing has been said about the force required to start or to stop the flow of current That such force is different from that to maintain a steady flow may be surmised from the analogous mechanical case of setting into motion or bringing to rest a material body such as, for ex ample a flywheel In dealing with alternating currents, we are dealing with varying magnitudes and directions of current flow Hence the electrical forces required for the maintenance of a steady flow of alternating current in a circuit will conceivably be different in general from those required to maintain a steady flow of direct current through that circuit Let us now consider what takes place as the magnitude and direction of a current flowing through a coil changes, and what effect such changes in current flow will have on the effective voltage required to maintain a given effective flow of current

In Fig 101 are two coils, one within the other Let A, the inner coil, be connected to a battery through a double pole switch S The other coil B is connected to a voltmeter with its zero point at the center of its scale On closing the switch a current will rush through the winding of coil A, the primary coil of the arrange ment The voltmeter will indicate a momentary flow of current in coil B, the secondary coil This current dies out rapidly If the

switch is now suddenly opened, interrupting the flow of current in the primary coil A, the voltmeter will again indicate a momentary flow of current in the secondary coil B, but in the opposite direction. The momentary currents flowing in the secondary coil on making and breaking the primary circuit are induced currents, for there are no electrical connections between the coils. The electromotive forces tending to cause these momentary currents to

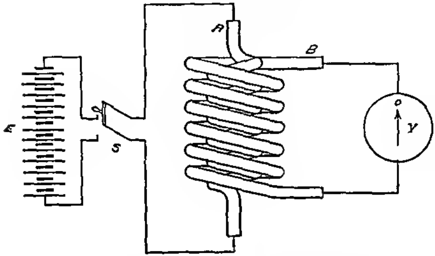

FIG 101 Arrangement of apparatus to demonstrate *mutual induction* A and B *are two coils, one within the other and electrically insulated from each* other, E is a battery, S, a double-pole switch, and V, a voltmeter

flow are induced electromotive forces, and the two electric circuits are said to possess the property of *Mutual Inductance* Obviously, a change of current flow in either will give rise to an induced emf in the other. Note that the direction of the current induced in the secondary winding was opposite to the current in the primary coil A on making the circuit, but in the same direction when the circuit was broken In both cases, the induced current tended to oppose the change taking place in the primary current As the current flowing in the primary increases, a magnetic field is gradually set up with the north pole at the near end of the coil as indicated in Fig 102. This magnetic field, during its establish-

ment, induces an emf in the secondary winding causing a current to flow which sets up a magnetic field opposing that which the primary current is establishing. When the current has reached a steady value and the magnetic field is no longer increasing, no cutting of the turns of the secondary coil by the lines of magnetic force takes place and the current in the secondary falls to zero. So long as the current remains constant, no opposing effect is exerted by the secondary. But as soon as the primary circuit is broken, the magnetic field collapses, cutting the turns of the secondary coil in a direction opposite to that in which the lines of

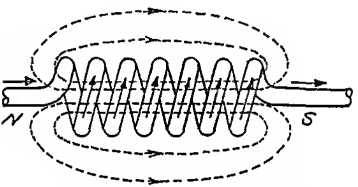

Fig 102 Schematic representation of the magnetic field set up about a coil through which a current is flowing

magnetic force cut the turns during the establishing of the field. Consequently the momentary induced secondary current will be in an opposite direction to that induced during the making of the primary circuit. The magnetic field of the secondary will now be additive with respect to the magnetic field of the primary. Thus the induced current always tends to prevent a change in the primary current. This reaction of the circuit is due to the *inductance* of the circuit and is comparable to inertia in the case of mechanical motion In view of the fact that a change in the current of either of the two coils induces a current in the other coil which tends to oppose the change, the two coils are said to have *mutual inductance* All of these phenomena are merely manifestations of

a law, first stated by Lenz, and called *Lenz's Law*. Stated briefly, this law is: An induced current is always in such a direction that its field *opposes any change* in the existing field.

Let us now consider a simple coil. We might assume that the coil has a resistance of 10 ohms and that the voltage impressed on it is 100 volts By means of an appropriate current recorder it will be observed that the current does not immediately rise to its final steady value of 10 amperes The rapidity with which it rises is a function of the number of turns in the coil For a coil of many turns, a greater time is required If the coil is wound on an iron core, still greater time is required, possibly as much as a second elapses before the steady state is reached Obviously the presence of a magnetic material such as iron enhances the delaying effect on the build-up of the current

The reason for the retardation of current flow is the inductance of the coil. As the current flows through the first turn of the coil, a magnetic field is set up During its establishment, the lines of magnetic force cut the succeeding turns of the coil, inducing an emf which opposes the establishment of the field If the core of the coil is of iron, the intensity of the field being established is greater, and consequently the emf induced is greater. This counter, or opposing, emf retards the establishment of the final steady current. Similarly when the circuit is opened, the *Self Inductance* of the circuit, as this property of a coil is called, tends to keep the current flowing This is achieved by the collapsing magnetic field inducing an emf to cause a current to flow in the same direction as that which established the field

During the growth of current in a coil there exists a counter emf as already explained In order that the phenomena taking place might be better comprehended, let us compute what the counter emf is at various times during the growth of a current If E is the impressed emf, e the counter emf induced in the coil by the growing current, and R the resistance of the coil, the current i at any instant is

$$i = \frac{E - e}{R}$$

A coil having a resistance of 11 ohms is wound on an iron core. In series with the coil is connected an ammeter A voltage of 110 volts is applied to the circuit. In the following table the current flow at various times after the switch was closed is given. Also in this table are given the counter emf's at these various instants When the current increases at its greatest rate, the induced emf is greatest; as the rate of increase of current decreases, the induced emf decreases When the current reaches its final steady value, 10 amperes, the counter emf is zero (Example taken from *Elements of Electricity* by Timbie Published by John Wiley and Sons, New York)

Time	Current	Counter EMF
0 sec	0 amp	110 0 volts
1	4 2	63 8
2	6 6	37 4
3	8 0	22 0
4	9 0	11 0
5	9 3	7 7
6	9 6	4 4
7	9 8	2 2
8	9 9	1 1
9	10 0	0
1 0	10 0	0

The unit of inductance is the *henry*, which is the inductance of a circuit when a change of one ampere per second sets up an induced emf of one volt The symbol for inductance is the letter L *

Let us now consider an alternating voltage impressed on a coil.

* The equations for the *self inductance* of a coil are

a With iron core.

$$L = \frac{1\ 26 N^2 \mu A}{10^8 l}$$

or

$$L = \frac{4\pi^2 N^2 r^2 \mu}{10^9 l}$$

Where L = self inductance in henrys
N = number of turns
μ = magnetic permeability of core

Since the impressed voltage is continuously changing in magnitude, the current flowing in the coil will never reach a final constant value. We have seen that whenever the current flowing through a coil having inductance changes, a counter emf is induced in the coil. Obviously, therefore, there is a counter emf being continuously induced in the coil if an alternating emf is impressed upon it. This induced voltage will tend to oppose any change in current flow. Consequently, the impedance of the coil to the flow of an alternating current will be greater than that to the flow of a direct current. The impedance exerted by a coil due to its inductance is called its *inductive reactance,* and is represented by the letter X with an L as a subscript (X_L). The mathematical equation giving the inductive reactance of a coil in terms of the self inductance of the coil and the frequency of the alternating current is $X_L = 2\pi f L$, in which L is the self inductance of the coil in henrys and f the frequency of the current in cycles per second. The inductive reactance X_L will be in ohms.*

A = section area of core in sq cms
l = length of core in cms
r = diameter of core in cms

b With air core

If the coil is a solenoid with a mean radius r, and a length l, with an air core ($\mu = 1$), the equation for self inductance may be written

$$L = \frac{4\pi^2N^2r^2}{10^9l}$$

The *mutual inductance* of two coils wound on the same core and with approximately the same diameter is:

$$M = \frac{4\pi^2N_1N_2r^2}{10^9l}$$

Where M = mutual inductance in henrys
N_1 = turns on one coil
N_2 = turns on the other coil
r = radius in cms of inner coil.

* According to the definition of the *henry,* a change of one ampere per second induces an emf of one volt in a circuit having an inductance of one *henry* We may then write the following equation·

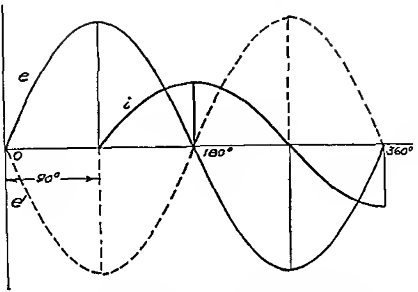

FIG 103 Current impressed emf and induced emf of a pure inductive circuit The current lags 90° behind the impressed voltage

In Fig 103 *curve i* represents the instantaneous values of the sinusoidal alternating current flowing in a coil, *curve* e^1, the instantaneous values of the induced or counter emf, and *curve e* the instantaneous values of the impressed emf required to overcome the induced emf You will note that the current reaches its maximum value 90 degrees later than does the impressed emf Hence the current flowing in a coil is said to be a lagging current The influence of resistance in the coil on the angle of lag of the current behind the voltage will be discussed in a later paragraph

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Average induced voltage = self inductance × rate of change of current, or in symbols

$$\text{Av E} = \text{L}\frac{\text{I}}{}$$

Therefore if the current is changing at the rate of 5 amperes per second in a circuit having a self inductance of 2 henrys, the average induced emf will be 2 × 5, or 10 volts

In the case of an alternating current, the current changes 4 times per cycle

Capacitance and Capacitive Reactance It was discovered at Leyden that a device consisting of parallel conductive plates separated by an insulator, possesses the ability of storing electricity On impressing a constant emf on such a device a current will flow momentarily As soon as the condenser, as such a device is called, is fully charged to the potential impressed upon it, the

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from zero to maximum from maximum to zero from zero to a maximum in the opposite direction and from this maximum to zero If the number of cycles per second is f the time for one cycle is $1/f$ seconds Therefore the time for each change is ¼ the time for each cycle or $1/(4f)$ seconds The rate of change of current must then be I_M divided by $1/(4f)$ or $4\,f\,I_M$ amperes per second The expression I/t must equal $4\,f\,I_M$ Hence Av $E = 4\,f\,L\,I_M$. The average value of the voltage is 0 636 times E_M the maximum value Therefore $0\,636\,E_M = 4fLI_M$ or $E_M = 6\,28\,f\,L\,I_M$. Since 6 28 equals 2π $E_M = 2\pi\,f\,L\,I_M$ Let us now multiply both sides of this equation by 0 707 obtaining

$$0\,707\,E_M = (2\pi\,f\,L) \times 0\,707\,I_M$$

Since $0\,707\,E_M = E_{eff}$ and $0\,707\,I_M = I_{eff}$ we have

$$E_{eff} = 2\pi\,f\,L\,I_{eff}$$

The impressed voltage must be equal in magnitude to the induced voltage in order that current may flow The current that flows through such a circuit will be opposed by the inductive reactance assuming the coil to have no ohmic resistance Therefore

$$I = \frac{E}{X_L}$$

But $$E = 2\pi fLI$$

Hence $$I = \frac{2\pi fLI}{X_L} \text{ or}$$

$$X_L = 2\pi fL$$

Example 1 A coil consists of 250 turns having a mean radius of 10 cm and a length of 20 cm. What is the self inductance of the coil if the core is of air?
Solution

$$L = \frac{4\pi^2 N^2 r^2}{10^9 l} = \frac{4\pi^2 \times 250 \times 250 \times 10 \times 10}{10^9 \times 20} \text{ henrys} = 0\,0123 \text{ henrys} = 12.3 \text{ millihenrys}$$

Example 2 If a 60-cycle alternating voltage of 110 volts effective is impressed on this coil what current will flow?
Solution

$$X_L = 2\pi fL = 2\pi \times 60 \times 0\,0123 \quad 4\,64 \text{ ohms}$$

$$I_{eff} = \frac{E_{eff}}{X_L} = \frac{110}{4\,64} = 23\,7 \text{ amperes}$$

charging current ceases to flow The charging of a condenser may be likened to the displacement of a rubber diaphragm in a hydraulic system On applying pressure to such a diaphragm the diaphragm is displaced until it exerts a counter pressure equal to the pressure impressed upon it If now the pressure is removed, the diaphragm will return to its original position In a manner analagous to this, a condenser may be charged and discharged The discharge does not take place in the case of a condenser, however, unless an electrically conductive path for the flow of current is provided, extending from one plate to the other This conductor may be ionized gas, an electrolytic solution, or a metallic conductor

We have likened inductance to inertia in a mechanical system Capacitance, or the ability of a condenser to store electricity, may be likened to elasticity in a mechanical system The similarity between electrical capacitance and mechanical elasticity is easily understood from the hydraulic analogy used in the preceding paragraph to explain the action of a condenser

Inductance makes its presence known when the current changes, capacitance when the voltage changes The capacitance of a condenser is expressed in terms of the quantity of electricity it will hold per volt of applied electrical pressure The quantity of electricity is expressed in coulombs, one coulomb being the quantity of electricity represented by one ampere flowing for one second When a condenser holds one coulomb of electricity for every volt pressure across its terminals, the condenser is said to have a capacitance of 1 *farad* Stated another way, a condenser has a capacitance of one farad when the addition of one coulomb raises its voltage one volt Expressed in symbols

$$C\ (\text{farads}) = \frac{Q\ (\text{coulombs})^*}{E\ (\text{volts})}$$

* It can be readily shown that the greater the area of the plates of a condenser the greater its capacitance, and the greater the distance between the plates the lower its capacitance This may be expressed algebraically as follows $C = KA/(4\pi d)$ where C is capacitance in statfarads A the inside area of plates d the distance between plates and K a constant depending upon the insulating material between the plates This constant is called the *dielectric constant* of the insulating material

The dielectrics or insulating media between the plates of condensers do not

Capacitance in an electric circuit acts like an air chamber in a pump circuit It tends to oppose any pressure change and hence reacts to maintain the pressure constant As long as the voltage impressed on a condenser is rising, current will flow into the condenser. And the flow of current will be greatest when the

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all have the same dielectric power In the following table are given the dielectric constants of various materials (From *Scientific Encyclopedia*, published by D Van Nostrand Co Inc New York, 1938)

DIELECTRIC CONSTANTS OF VARIOUS MATERIALS

Material	K
Air	1 000
Alcohol	28 4
Glass (flint)	9 9
Linseed Oil	3.3
Mica	5 7
Paraffin	2 1
Rubber	2 2
Water	81 1

The capacitance of a plate condenser can be computed from the general equation

$$C = \frac{KA}{4\pi d \times 9 \times 10^5} = \frac{885AK}{10^{10}d},$$

where C = capacitance in microfarads (1 farad = 1 000 000 microfarads), abbreviated μf,

A = area of all dielectric between plates in sq cms ,
d = average thickness of dielectric in cms
K = dielectric constant

Example 1 What is the capacitance of a condenser consisting of 200 plates of lead foil, if the dielectric separating the plates is mica 0 1 mm. in thickness and 10 cms by 15 cms in area?

Solution

$$C = \frac{885 \times 200 \times 10 \times 15 \times 5\ 7}{10^{10} \times 0\ 01} = 1.5 - \text{microfarads}$$

Example 2 What charge will condenser in Example 1 hold under a pressure of 220 volts?

Solution

$$C\ (\text{farads}) = \frac{Q\ (\text{coulombs})}{E\ (\text{volts})}$$

Charge

$$Q = C \times E = \frac{1\ 5}{1{,}000{,}000} \times 220 = 33 \times 10^{-5} \text{ coulombs or 330 microcoulombs}$$

voltage is rising most rapidly A sinusoidal voltage is rising most rapidly when it passes through zero value Hence, the flow of current into the condenser will be a maximum at this point When the voltage reaches its maximum value, the rate at which the voltage changes is zero and hence the current flow will be zero As the voltage decreases, current will flow out from the condenser, becoming a maximum when the voltage passes through

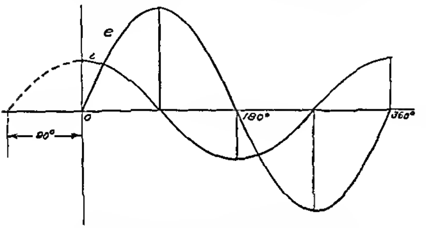

Fig 104 Current and impressed emf of a pure capacitive circuit The current leads the impressed voltage by 90°

zero value Then as the sinusoidal voltage becomes negative, the rate of change of voltage becomes less and less until a maximum negative voltage is reached At this point the rate of change of voltage is again zero and the current flow from the condenser becomes zero As the voltage begins to rise from this value, current will again flow into the condenser, becoming a maximum when the voltage reaches the zero value, which is the time the rate of change of voltage is greatest Thus we have completed a complete cycle of charging and discharging the condenser It is evident from this discussion that the current reaches a maximum before the voltage does In Fig 104 is shown the phase relationship between an alternating voltage impressed on a condenser and the resulting current flow It is readily seen that the current leads the voltage by 90 electrical degrees

If an alternating current ammeter is connected in series with a condenser and an alternating emf is impressed on the circuit, the ammeter will indicate a steady alternating current flow. If the voltage is increased but its frequency is kept constant, the current flow will increase in direct proportion to the impressed voltage. If the condenser is a perfect condenser with no power loss in the dielectric, the only impedance exerted by it to the flow of an alternating current is the *capacitive reactance* of the condenser, as the opposition the condenser offers to the flow of an alternating current is called. The current-voltage relation in such a circuit is expressed by the following equation:

$$\text{Current} = \frac{\textit{voltage}}{\textit{capacitive reactance}},$$

or in symbols

$$I = \frac{E}{X_c}$$

In using this equation, as in using the equation showing the relation between current and voltage in a coil having inductance, corresponding values of the current and voltage must be used: the maximum value of the current with the maximum value of the voltage, or the effective current with the effective voltage.

If the impressed voltage is kept constant but its frequency is varied, it will be found that the current increases as the frequency increases. Therefore, as the frequency increases the capacitive reactance must decrease. This is in contra-distinction to the inductive reactance of a coil which increases with increase in frequency. It can be shown that the capacitive reactance of a condenser in ohms is equal to $1/2\pi fC$, in which C is the capacitance of the condenser in farads and f the frequency of the current in cycles per second.*

* *Capacitive Reactance.* In a circuit containing a capacitance such as a condenser, the current charges and discharges the condenser four times per cycle. The current first charges the condenser positively; then discharges the condenser, charges it negatively, and then discharges it. The cycle then repeats and continues to repeat as long as an alternating emf is impressed on the circuit.

The time for each complete charge or discharge is $1/(4f)$ seconds. The quan-

Impedance. All electric circuits have ohmic resistance. When an alternating electromotive force is impressed on a circuit, the opposition to the flow of current will be made up of this resistance plus the reactance that may or may not be present. The reactance,

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tity of charge in the condenser in coulombs is $Q = EC$, E being the voltage to which the condenser is charged and C the capacitance of the condenser in farads.

However, the quantity of electricity that flows into a condenser, like the quantity of water that flows into a tank, must be equal to the average rate of flow times the time of flow.

Hence

$$Q = \text{Av. } I \times t = \text{Av. } I \times \frac{1}{4f}$$

But since

$$Q = E_M C$$

$$E_M C = \frac{\text{Av. } I}{4f} \quad \text{and} \quad E_M = \frac{\text{Av. } I}{4fC}$$

We have shown that for a sinusoidal alternating current

$$\text{Av. } I = 0.636\, I_M$$

Therefore

$$E_M = \frac{0.636\, I_M}{4fC} = \frac{I_M}{6.28fC} = \frac{I_M}{2\pi fC} \quad \text{or} \quad E_{eff} = \frac{I_{eff}}{2\pi fC}$$

The voltage required to send a current through a circuit that contains capacitive reactance only is

$$E_{eff} = X_C I_{eff}$$

Where

$$X_C = \text{capacitive reactance}$$

Therefore

$$X_C I_{eff} = \frac{I_{eff}}{2\pi fC} \quad \text{or} \quad X_C = \frac{1}{2\pi fC}$$

Example 1. What is the capacitive reactance of an alternating current circuit containing 20 microfarads capacitance if the frequency of the applied emf is 60 cycles per second?

Solution.

$$X_C = \frac{1}{2\pi fC} = \frac{1}{6.28 \times 60 \times 20 \times 10^{-6}} = 113.7 \text{ ohms}$$

Example 2. What current will 550 volts effective force through the circuit in Example 1?

Solution.

$$I_{eff} = \frac{E_{eff}}{X_C} = \frac{550}{113.7} = 4.83 \text{ amperes}$$

as has been shown, may be either that due to inductance or that due to capacitance, or that due to both, if both inductance and capacitance are present in the circuit. The total impedance, however, cannot be determined by simple addition of the resistance and the reactance We have already seen that reactance alone in a circuit causes current to lead or lag behind the voltage 90°, depending respectively on whether the reactance is capacitive or inductive.

Let us consider a series circuit consisting of an ohmic resistance R, an inductive reactance X_L, and a capacitive reactance X_C Let the effective current be I. This current will flow through each of these three circuit elements, since the elements are connected in series

In Fig 105 the line with the closed arrow head represents to scale the current I The voltage required to overcome the ohmic resistance is IR This voltage and the current are in phase. Therefore, the line designated IR and having a length that is proportional to the value of IR, is drawn to coincide with the current vector.* The voltage to overcome the inductive reactance equals IX_L and leads the current by 90°, or, what amounts to the same thing, the current I lags 90° behind the voltage Therefore, a vector representing the voltage IX_L is drawn beginning at the extremity of the vector IR and making a positive angle of 90°

* *Vector and Scalar Quantities* By the term *vector* is meant a straight line whose length is proportional to the magnitude of the quantity to be represented and whose direction is the direction in which the quantity is acting Quantities represented by vectors are velocity, force, distance, etc.—such quantities as have not only magnitude but also direction Therefore, a velocity of 20 miles per hour due east, a force of 10 pounds acting on a body at 30° with respect to the horizontal plane along which the body moves or on which the body rests, a displacement of the body a distance of 10 feet along the horizontal plane, are examples of vector quantities

If a quantity has only magnitude but no direction of action, it is known as a *scalar* quantity and can be represented by a line whose length is proportional to the magnitude of the quantity but whose direction is immaterial Such quantities as energy and power, to cite two examples, are scalar quantities

In alternating current problems, vectors are used extensively, for, as has been shown, phase differences occur between voltages and currents To represent the magnitudes and the phase differences of such quantities vectors are employed.

with respect to the current vector I The voltage drop over the capacitive reactance equals IX_C, and this voltage lags behind the current Beginning at the extremity of the vector IX_L, a vector is

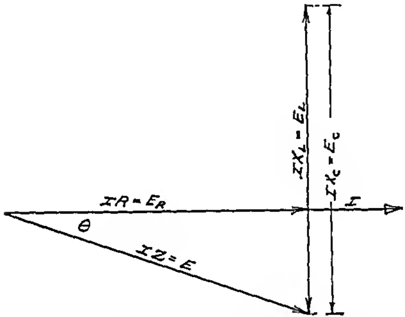

FIG 105 Vector diagram of a series circuit The vector E_L (the drop over the inductive reactance) makes an angle of 90° with the current vector I because this voltage leads the current by 90° Since the voltage drop over the capacitive reactance E_C lags 90° behind the current the vector representing E_C is drawn to make an angle of —90° with the current vector I The resistance drop is in phase with the current and hence E_R is drawn parallel to the vector I The total impressed emf is E or the vector drawn from initial point of the vector E_R to the terminal point of the vector E_C The angle θ made by the vector E with the current vector I is the angle of phase difference between the impressed voltage and the current In this case θ is negative showing that the voltage lags behind the current or what amounts to the same thing the current leads the voltage The resultant effect of the inductance and capacitance in the circuit is that of a capacitance

drawn making a negative angle of 90° with respect to the current A line drawn from the origin of the resistance drop vector to the extremity of the vector representing the voltage drop over the capacitive reactance will represent the total voltage impressed

on the circuit; its length, the magnitude of the voltage, and the angle between it and the current vector the phase difference between the total impressed voltage and the current. In Fig. 105 the effect of the capacitive reactance is shown as sufficiently great to cause the voltage to lag behind the current, or the current to lead the voltage.

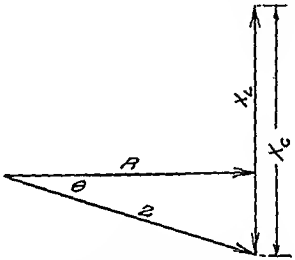

FIG 106 Resistance, reactance, and impedance diagram of a series circuit

If each of the vectors making up the closed diagram in Fig 105 is divided by the same quantity, I, a similar diagram will be obtained. Fig. 106. The straight lines forming this diagram will represent to scale R, X_L, X_C, and Z—the last or closing line of the diagram representing the total impedance obtained by dividing the impressed voltage by the current.

Referring to Fig. 106, it is seen that the resultant reactance X of the circuit equals $X_L - X_C$. If X_C is greater than X_L, the sign of the resultant reactance X will be negative, indicating that the resultant reactance is a capacitive reactance. From the diagram we can write the following equation:

$$Z^2 = R^2 + X^2$$

or

$$Z = \sqrt{R^2 + X^2}$$

Since

$$X = X_L - X_C,$$
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

But

$$X_L = 2\pi fL \text{ and } X_C = \frac{1}{2\pi fC}$$

Therefore

$$Z = \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2} \text{ ohms}$$

Example 1. A series A C circuit consists of a resistance of 4 ohms, an inductive reactance of 5 ohms, and a capacitive reactance of 8 ohms What is the impedance of the circuit?
Solution.

$$X = X_L - X_C = 5 - 8 = -3 \text{ ohms}$$
$$Z = \sqrt{4^2 + (-3)^2} = \sqrt{25} = 5 \text{ ohms}$$

Exomple 2. What is angle of phase difference between the impressed voltage and the current in Example 1?
Solution.

$$\text{Cosine of angle} = \frac{R}{Z} = \frac{4}{5} = 0\ 80$$
$$\text{Angle} = 36°52'$$

The current leads the voltage, since X is negative; i e, the total reactance is capacitive in nature.

Ohm's Law. We are now prepared to write Ohm's Law for the alternating current circuit.

$$Z \text{ (Impedance in ohms)} = \frac{E \text{ (volts)}}{I \text{ (amperes)}},$$

or

$$\sqrt{R^2 + (X_L - X_C)^2} = \frac{E}{I},$$

or

$$\sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2} = \frac{E}{I}$$

Example 1. A series circuit consists of a resistance of 4 ohms, an inductance of 100 millihenrys, and a capacitance of 400 microfarads. What current will flow if an alternating emf of 220 volts and 60 cycle frequency is impressed on the circuit?
Solution.

$$R = 4 \text{ ohms}$$

$$X_L = 2\pi f L = 6\ 28 \times 60 \times 100 \times 10^{-3}$$
$$= 37\ 7 - \text{ohms}$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{6\ 28 \times 60 \times 400 \times 10^{-6}}$$
$$= 6\ 6 \text{ ohms}$$

$$Z = \sqrt{R^2 + X^2} = \sqrt{4^2 + 31\ 1^2} = \sqrt{1983\ 21} = 44\ 5 \text{ ohms}$$

$$I = \frac{E}{Z} = \frac{220}{44\ 5} = 4\ 9 \text{ amperes}$$

Power in Alternating Current Circuits. The power dissipated in a direct current circuit is equal in watts to the product of the current flowing through the circuit and the voltage drop over the circuit, or $P = EI$. Since by Ohm's Law $I = E/R$ and $E = IR$, we may also write the following expressions for power

$$P = I^2R \quad \text{and} \quad P = \frac{E^2}{R}$$

In the case of a circuit in which an alternating current is flowing, the rate at which energy is absorbed varies continuously. At any instant the power taken equals the product of the voltage at that instant and the current at that instant. The instantaneous power in watts, p, is therefore equal to the instantaneous voltage e times the instantaneous current i Knowing the voltage and the current and the phase difference between them, the power curve can be determined by multiplying corresponding instantaneous values of the current and voltage curves and plotting the product The average power is the average ordinate of the power curve The consideration of the average power consumed in an A C circuit divides itself into two parts: when the voltage and current are in phase and when they are out of phase.

Current and Voltage in Phase When an alternating voltage is applied to a pure resistance, the current that flows will be in phase with the voltage, being zero when the voltage is zero and a maximum when the voltage is a maximum In Fig 107 is shown the voltage wave and the resulting current wave when the circuit consists of a non inductive resistance R We may consider the sinusoidal waves of voltage and current generated by two vectors

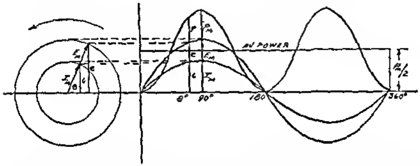

Fig 107 Voltage current, and power of a non inductive circuit (resistance only) *e* is the voltage *i* the current and *p* the power Note that at no time during the cycle does the power curve become negative This indicates that power is taken by the circuit and never returned

rotating about a common axis These vectors have magnitudes proportional to the maximum values of the voltage and current Since the current and voltage are in phase, the angular displacement between the vectors is zero degrees That is to say, the vectors coincide Let us now rotate these vectors in a counter-clockwise direction For successive angular displacements of these vectors let us plot the correspoodiog vertical components of the vectors, obtaining the current and voltage curves shown in the Fig 107

If we multiply corresponding instantaneous current and voltage values of the current and voltage curves, we shall obtain the power curve *p* It is evident that the average of the power is $P_M/2$, where P_M is the maximum value P_M however equals $E_M \times I_M$ Therefore

$$P_{av} = \frac{P_M}{2} = \frac{E_M \times I_M}{2} = \frac{E_M}{\sqrt{2}} \frac{I_M}{\sqrt{2}} = 0\ 707\ E_M \times 0\ 707\ I_M$$

or

$$P_{av} = E_{eff} \times I_{eff}$$

Also

$$E_{eff} = I_{eff}R$$

Therefore

$$P_{av} = I_{eff}^2 R.$$

Current and Voltage out of Phase. Let us now consider a circuit in which the current and voltage are not in phase. In Fig 108 are

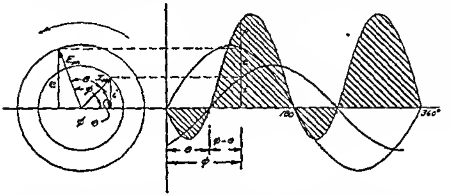

FIG 108 Voltage, current, and power of an inductive circuit (i e, a circuit having inductance as well as resistance) The curves *e*, *i*, and *p* show, respectively, the instantaneous voltage, the instantaneous current, and the instantaneous power In this case the power curve becomes negative During the time the curve is negative, power is returned to the circuit from the magnetic field about the coil in which, during the rest of the cycle, energy had been stored The total energy per cycle taken by the circuit is proportional to the area under the power curve and above the horizontal axis, that returned per cycle by the circuit is proportional to the area of the negative portions of the power curve The difference between these areas is proportional to the net power absorbed by the circuit.

plotted the current and voltage variations in a circuit possessing inductance as well as resistance In this circuit the resistance and inductance are such that the current lags θ degrees behind the voltage.

Proceeding as before, we determine the power curve *p*. It is seen that during certain periods the instantaneous power is negative. During these periods, power is not being consumed by the

circuit, but is being returned to it from the magnetic field in which energy has been stored If no ohmic resistance had been present in the circuit, as much power would be returned as had been stored in the magnetic field For that reason, an inductive reactance is frequently employed to limit and control the flow of alternating current through lamps and other devices, instead of using a resistor which would consume appreciable power A re

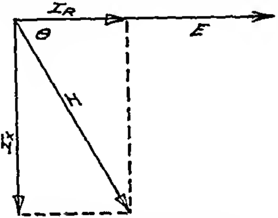

FIG 109 Vector diagram of effective current and effective voltage of circuit of Fig 108

actance for this purpose consists essentially of a coil with a moveable laminated iron core The position of the core determines the self inductance of the coil and consequently the reactance the coil opposes to the flow of an alternating current Therefore, by varying the position of the core the flow of current through lamps or other devices connected in series with the coil can be varied without the dissipation of excessive power in the current control

In Fig 109 is a vector diagram of the effective current and effective voltage of the circuit The phase difference between the voltage and current is θ degrees with the current lagging The vectors therefore are drawn with an angle of θ degrees between them The vector E is drawn horizontally and the vector I in a direction making an angle of minus θ degrees with respect to the

voltage vector, minus θ degrees because the current lags behind the voltage.

The current vector I may be considered to be composed of two components: one, I_R, which is in phase with the voltage; and the other, I_X, which is 90° out of phase with the voltage

We have already seen that power is required only to maintain the current which is in phase with the voltage and that no power is consumed when the current is 90 degrees out of phase with the voltage. Therefore, the average power consumed in the circuit under consideration is equal in watts to the product of the effective voltage and the component of the total effective current which is in phase with the voltage This particular component is obviously the projection of the current vector upon the voltage vector. From the definition of the cosine of an angle, this component is readily seen to be equal to $I \cos \theta$, I without a subscript being the effective value of the total current The average consumption of power by the circuit is then $P_{av} = EI \cos \theta$.

The term *cos* θ is called the *power factor* of the circuit; and the product EI is called the *apparent power* of the circuit. Only when θ is zero and the cosine θ unity, is the apparent power equal to the actual power This is the case when the circuit contains only resistance and no reactance Under certain conditions a circuit containing both inductance and capacitance in series with a resistance may have a unity power factor; this occurs when the inductive reactance equals the capacitive reactance. These two quantities have already been shown to act 180° out of phase with respect to each other, the one tending to neutralize the other If the two are numerically equal, they will cancel each other, leaving only resistance to oppose the flow of the current The circuit then behaves as a non-inductive circuit, and the current that flows will be in phase with the impressed voltage

Equivalent expressions for the power taken by an alternating current circuit are:

(1) $P = EI_R$, in which I_R is the energy component of the total current, *i e*, the component which is in phase with the voltage,

(2) $P = E_R I$, in which E_R is the component of the impressed voltage that is in phase with the current; and

(3) $P = I^2R$ *

SERIES ALTERNATING CURRENT CIRCUITS. Circuit elements such as resistances, inductances, and capacitances may be connected in two different ways: in series or in parallel. Let us first consider the series connection of such elements

Resistances in Series. If a number of non-inductive resistances, R_1, R_2, R_3, etc, are connected in series or in tandem, the total resistance R will be the arithmetical sum of the various component resistances. That is

$$R = R_1 + R_2 + R_3 + \text{etc. ohms}$$

Inductances in Series. If a number of inductances, L_1, L_2, L_3, etc, are connected in series, the total inductance will be the arithmetical sum of the component inductances. That is

$$L = L_1 + L_2 + L_3 + \text{etc. henrys}$$

Capacitances in Series If a number of capacitances, C_1, C_2, C_3, etc., are connected in series, the reciprocal of the total capacitance will be equal to the arithmetical sum of the reciprocals of the component capacitances. That is

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{etc. reciprocal farads}$$

Inductive Reactances in Series. If we multiply both sides of the equation for total inductance by $2\pi f$, we obtain

$$2\pi fL = 2\pi fL_1 + 2\pi fL_2 + 2\pi fL_3 + \text{etc ohms}$$

The total inductive reactance of the series circuit is then equal to the arithmetical sum of the inductive reactances due to the component inductances; or

$$X_L = X_{L_1} + X_{L_2} + X_{L_3} + \text{etc. ohms}$$

* The derivation of these expressions for power follows readily from relationships which have already been established

(1) $P = EI \cos\theta$ But $I \cos\theta = I_R$ ∴ $P = EI_R$

(2) $P = EI \cos\theta$ But $E \cos\theta = E_R$ ∴ $P = E_RI$

(3) $P = EI \cos\theta$ But $E = ZI$ and $\cos\theta = R/Z$ ∴ $P = ZI \cdot I \cdot (R/Z) = I^2R$

Capacitive Reactances in Series. Let us now divide both sides of the equation for total capacitance by $2\pi f$, obtaining

$$\frac{1}{2\pi fC} = \frac{1}{2\pi fC_1} + \frac{1}{2\pi fC_2} + \frac{1}{2\pi fC_3} + \text{etc. ohms}$$

The total capacitive reactance of a series circuit is then equal to the arithmetical sum of the capacitive reactances due to the component capacitances; or

$$X_C = X_{C_1} + X_{C_2} + X_{C_3} + \text{etc. ohms}$$

Impedance of a Series Circuit. The total impedance of a circuit has already been shown to be equal to the square root of the sum of the squares of the total resistance and the total reactance of the circuit. After having computed in the manner described above the total resistance, the total inductive reactance, and the total capacitive reactance of a circuit, the total impedance can be readily computed by the equation

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \text{ ohms}$$

Example. A series circuit consists of the resistances 10 ohms, 20 ohms, and 15 ohms; the inductances 50 millihenrys and 100 millihenrys; and the capacitances 50 microfarads and 100 microfarads. Find: (a) the total resistance; (b) the total inductance; (c) the total inductive reactance if the frequency of the impressed voltage is 60 cycles per second; (d) the total capacitance; (e) the total capacitive reactance for a frequency of 60 cycles per second; (f) the total impedance; (g) the phase difference between the impressed emf and the resulting current, stating whether the current lags behind or leads the voltage; (h) the power factor of the circuit; (i) the current flow for an impressed effective voltage of 220 volts, 60 cycles; (j) the apparent power; (k) the real power; and (l) construct a vector diagram showing the current, the voltage drop over each circuit element, and the total voltage, indicating in the diagram the angle of phase difference between the total impressed voltage and the current

Solution.

(a) Total resistance $R = R_1 + R_2 + R_3 = 10 + 20 + 15 = 45$ ohms.

(b) Total inductance $L = L_1 + L_2 = 50 + 100 = 150$ mh., or 0 15 henry

(c) Total inductive reactance $X_L = 2\pi f\, L = 2\pi \times 60 \times 0\ 15 = 56\ 5$ ohms

(d) Total capacitance C

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_1} = \frac{1}{50} + \frac{1}{100} = \frac{3}{100} \text{ reciprocal microfarads}$$

$$C = \frac{100}{3} \text{ microfarads} = \frac{100}{3} \times 10^{-6} \text{ farads}$$

(e) Total capacitive reactance

$$X_C = \frac{1}{2\pi f C} = \frac{3}{2 \times \pi \times 60 \times 100 \times 10^{-6}} = \frac{10^3}{4\pi} = 80\ 5 \text{ ohms}$$

(f) Total impedance

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{45^2 + (56\ 5 - 80\ 5)^2} = 51 \text{ ohms}$$

(g) Cosine of angle of phase difference $= R/Z = 45/51 = 0\ 882$ therefore 8, the angle of phase difference is 28° The current leads the voltage because the total capacitive reactance is greater than the total inductive reactance

(h) Power factor of the circuit $= \cos 8 = 0\ 882$

(i) Current $I = E/Z = 220/51 = 4\ 33$ amperes

(j) Apparent power $E \times I = 220 \times 4\ 33 = 950$ volt amperes

(k) Real power $P = EI \cos 8 = 220 \times 4\ 33 \times 0\ 882 = 837$ watts

(l) Vector diagram See Fig 110

PARALLEL ALTERNATING CURRENT CIRCUITS The second manner in which circuit elements may be connected is in parallel or in shunt as this manner of connection is sometimes called When connected in parallel all the circuit elements have the same voltage impressed on them, the currents flowing through the various branches however are not necessarily the same the flow through each branch being determined by the impedance of that branch In contra distinction the current through the various elements when connected in series is the same but the total impressed voltage over the series connection is the vector sum of the voltage drops over the component circuit elements

Resistances in Parallel. If a number of non-inductive resistances, R_1, R_2, R_3, etc., are connected in parallel or in shunt, the total resistance is determined in the same manner as it would be if the circuit were considered a parallel direct current circuit.

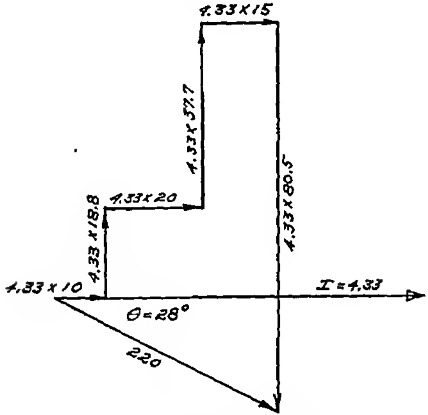

FIG 110 Vector diagram of a series circuit containing resistance, inductive reactance, and capacitive reactance

That is, the reciprocal of the total resistance equals the sum of the reciprocals of the resistances of the various branches Expressed in the form of an equation,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{etc}$$

Inductances in Parallel Inductances connected in parallel are added like resistances, the reciprocal of the total inductance of

the parallel circuit being equal to the sum of the reciprocals of the inductances of the various branches. That is,

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \text{etc.}$$

Capacitances in Parallel Capacitances in parallel are added directly, the total capacitance being equal to the sum of the capacitances of the various branches That is,

$$C = C_1 + C_2 + C_3 + \text{etc.}$$

Conductance, Susceptance, and Admittance of a Circuit. The total current flowing through a circuit has two components at right angles to each other (*i e.,* 90° out of phase with respect to each other). one, an energy component which is in phase with the voltage impressed on the circuit; and the other, a wattless component which is 90° out of phase with the voltage.

The *conductance* of a circuit is defined as that quantity which, when multiplied by the voltage, will give the energy component of the current Expressed in the form of an equation, $g\,E = I_R$, in which g is conductance in mhos, E impressed emf in volts, and I_R the energy component of the current. We have already shown that the energy component of the current is equal to the total current I multiplied by the cosine of the angle of lag or lead Expressed in symbols,

$$I_R = I \cos\theta = I\frac{R}{Z} = I\frac{R}{\sqrt{R^2 + X^2}}$$

But

$$I = \frac{E}{Z} = \frac{E}{\sqrt{R^2 + X^2}}$$

Therefore

$$gE = \frac{R}{\sqrt{R^2 + X^2}}\,\frac{E}{\sqrt{R^2 + X^2}}$$

or

$$g = \frac{R}{R^2 + X^2}\ \text{mhos}$$

The *susceptance* of a circuit is defined as that quantity which, when multiplied by the voltage, will give the wattless component

of the current Proceeding in a similar manner to that outlined above, we obtain for susceptance the expression

$$b = \frac{X}{R^2 + X^2} \text{ mhos}$$

The *admittance* of a circuit is defined as that quantity which, when multiplied by the impressed voltage, will give the total current Expressed in symbols,

$$yE = I$$

The total current is the vector sum of its components; hence,

$$I^2 = I_R{}^2 + I_X{}^2$$

Substituting in this equation we obtain,

$$(yE)^2 = (gE)^2 + (bE)^2$$

Whence

$$y^2 = g^2 + b^2$$

and

$$y = \sqrt{g^2 + b^2}$$

Since

$$I = \frac{E}{Z}$$

$$y = \frac{1}{Z}$$

Solution of a Parallel Circuit The total current taken by a parallel circuit is the vector sum of the currents taken by the various branches The current taken by each branch can be considered as made up of a component in phase with the voltage and one at right angles to it Since the same voltage is impressed on all the branches, the energy components of the currents of all the branches are in phase and so may be added directly And so may all the wattless components, since they are all at right angles to the voltage and hence are in phase or 180° out of phase with each other * Therefore,

$$I^2 = (I_{R_1} + I_{R_2} + I_{R_3} + \qquad)^2 + (I_{X_1} + I_{X_2} + I_{X_3} + \qquad)^2,$$

* The wattless components are added algebraically if the wattless components due to inductive reactance are considered positive then those due to capacitive reactance, which are 180° out of phase with the former, must be considered negative

in which I_{R_1} and I_{X_1} are respectively the energy and the wattless components of the current in branch 1, I_{R_2} and I_{X_2} in branch 2, etc

Since

$$I = yE, \quad I_{R_1} = g_1E, \quad I_{X_1} = b_1E, \text{ etc}$$

$$(yE)^2 = (g_1E + g_2E + \quad)^2 + (b_1E + b_2E + \quad)^2$$

From this we obtain the total admittance y in terms of the conductances and the susceptances of the branches, or

$$y^2 = (g_1 + g_2 + g_3 + \quad)^2 + (b_1 + b_2 + b_3 + \quad)^2$$

This may be written

$$y^2 = g^2 + b^2,$$

in which

$$g = g_1 + g_2 + g_3 + \quad ,$$

and

$$b = b_1 + b_2 + b_3 +$$

Since $y = 1/Z$, the impedance of the parallel circuit is

$$Z = \frac{1}{y} = \frac{1}{\sqrt{g^2 + b^2}} \text{ ohms}$$

Example A parallel circuit consists of three branches branch 1, of a resistance of 3 ohms in series with an inductive reactance of 4 ohms, branch 2, of a resistance of 4 ohms and a capacitive reactance of 3 ohms, branch 3, of a resistance of 4 ohms, an inductive reactance of 5 ohms, and a capacitive reactance of 2 ohms The voltage impressed on the circuit is 110 volts Find (a) the impedance of each branch, (b) the current taken by each branch, (c) the power factor of each branch, (d) the power taken by each branch, (e) the conductance and susceptance of each branch, (f) the total conductance and susceptance, (g) the admittance of the parallel circuit, (h) the total current, (i) the apparent power, (j) the power factor of the parallel circuit, and (k) the total power

Solution

(a)

$$Z_1 = \sqrt{R_1^2 + X_1^2} = \sqrt{3^2 + 4^2} = \sqrt{25} = 5 \text{ ohms}$$

$$Z_2 = \sqrt{R_2^2 + X_2^2} = \sqrt{4^2 + (-3)^2} = \sqrt{25} = 5 \text{ ohms}$$

$$Z_3 = \sqrt{R_3^2 + X_3^2} = \sqrt{4^2 + (5 - 2)^2} = \sqrt{25} = 5 \text{ ohms}$$

(b)
$$I_1 = \frac{E}{Z_1} = \frac{110}{5} = 22 \text{ amps}$$
$$I_2 = \frac{E}{Z_2} = \frac{110}{5} = 22 \text{ amps}$$
$$I_3 = \frac{E_3}{Z_3} = \frac{110}{5} = 22 \text{ amps}$$

(c)
$$(\text{P F})_1 = \cos\theta_1 = \frac{R_1}{Z_1} = \frac{3}{5} = 0.6$$
$$(\text{P F})_2 = \cos\theta_2 = \frac{R_2}{Z_2} = \frac{4}{5} = 0.8$$
$$(\text{P F})_3 = \cos\theta_3 = \frac{R_3}{Z_3} = \frac{4}{5} = 0.8$$

(d)
$$P_1 = EI_1 \cos\theta_1 = 110 \times 22 \times 0.6 = 1452 \text{ watts}$$
$$P_2 = EI_2 \cos\theta_2 = 110 \times 22 \times 0.8 = 1936 \text{ watts}$$
$$P_3 = EI_3 \cos\theta_3 = 110 \times 22 \times 0.8 = 1936 \text{ watts}$$

(e)
$$g_1 = \frac{R_1}{R_1^2 + X_1^2} = \frac{3}{3^2 + 4^2} = \frac{3}{25} = 0.12 \text{ mhos}$$
$$b_1 = \frac{X_1}{R_1^2 + X_1^2} = \frac{4}{3^2 + 4^2} = \frac{4}{25} = 0.16 \text{ mhos}$$
$$g_2 = \frac{R_2}{R_2^2 + X_2^2} = \frac{4}{4^2 + (-3)^2} = \frac{4}{25} = 0.16 \text{ mhos}$$
$$b_2 = \frac{X_2}{R_2^2 + X_2^2} = \frac{-3}{4^2 + (-3)^2} = \frac{-3}{25} = -0.12 \text{ mhos}$$
$$g_3 = \frac{R_3}{R_3^2 + X_3^2} = \frac{4}{4^2 + (5-2)^2} = \frac{4}{25} = 0.16 \text{ mhos}$$
$$b_3 = \frac{X_3}{R_3^2 + X_3^2} = \frac{(5-2)}{4^2 + (5-2)^2} = \frac{3}{25} = 0.12 \text{ mhos}$$

(f)
$$g = g_1 + g_2 + g_3 = 0.12 + 0.16 + 0.16 = 0.44 \text{ mhos}$$
$$b = b_1 + b_2 + b_3 = 0.16 - 0.12 + 0.12 = 0.16 \text{ mhos}$$

(g) $y = \sqrt{g^2 + b^2} = \sqrt{(0\ 44)^2 + (0\ 16)^2} = 0\ 468$ mhos

(h) $I = yE = 0\ 468 \times 110 = 51\ 48$ amperes

(i) $P_{app} = EI = 110 \times 51\ 48 = 5662\ 8$ volt amps

(j) $P\,F = \frac{g}{y} = \frac{0\ 440}{0\ 468} = 0\ 94 +$

(k) $P = EI \times P\,F = 110 \times 51\ 48 \times 0\ 94 = 5323 +$ watts

Note The total power should be equal to the sum of the watts taken by the various branches The power should then equal 1452 watts plus 1936 watts plus 1936 watts or 5324 watts This value agrees with that computed for the entire circuit and serves as a check of our computation

Resonance in Series Circuits Under *Inductive Reactance* and *Capacitive Reactance* it was shown that an inductance in a circuit causes a lagging current, whereas a capacitance causes a leading current The inductive reactance hence tends to counteract the effect of a capacitive reactance Should the inductive and capacitive reactances be equal, the one would neutralize the other, making the resultant reactance of the series circuit zero Under such conditions, the impedance of the circuit would consist only of the ohmic resistance The ohmic resistance alone then would limit the flow of current on impressing an emf on the circuit The voltage drop over the inductance would be the same as that over the capacitance, but might be many times the voltage impressed on the entire circuit In fact, the voltage drop may become high enough to rupture the dielectric of the condenser

A series circuit is said to be in resonance when its capacitive reactance is equal to its inductive reactance We have learned that the inductive reactance X_L equals $2\pi fL$, and the capacitive

$$X_C = \frac{1}{2\pi fC}$$

For resonance

$$X_L = X_C \quad \text{or} \quad 2\pi fL = \frac{1}{2\pi fC}$$

Solving for f, the resonant frequency, we obtain

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Example. A series circuit consists of a capacitance of 50 microfarads, an inductance of 0.15 henry, and a resistance of 6 ohms. The impressed voltage is 125 volts Compute for various frequencies from 20 to 100 cycles per second: (a) the capacitive reactance X_C; (b) the inductive reactance X_L; (c) the total reactance X (equals $X_L—X_C$); (d) the impedance Z; (e) the current I; (f) the voltage drop over the resistance E_R (equals IR); (g) the voltage drop over the capacitive reactance E_C (equals IX_C); and (h) the voltage drop over the inductive reactance E_L (equals IX_L). Compute the resonant frequency using the equation for this frequency which was given in the foregoing paragraph. Then compute for the resonant frequency the various values requested in (a) to (b) inclusive Plot X_C, X_L, X, and I against frequency.

Solution In the following table the various computations called for in the problem are recorded In Fig 111 the various reactances and the current are plotted against frequency.

RESONANCE IN A SERIES CIRCUIT

		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Frequency f	R	$X_C = \frac{1}{2\pi f C}$	$X_L = 2\pi f L$	$X = X_L - X_C$	$Z = \sqrt{R^2 + X^2}$	$I = \frac{E}{Z}$	$E_R = IR$	$E_C = IX_C$	$E_L = IX_L$
20	6	−159	18 8	−140 3	140 3	0 89	5 3	142	16 8
30	6	−106	28 2	− 77 8	78	1 60	9 6	170	45
40	6	− 79 5	37 7	− 41 8	42 2	2 96	17 8	235	115
50	6	− 63 6	47 1	− 16 5	17 6	7.1	42 6	452	335
58 1*	6	− 54 7	54 7	0	6	20 83	125	1140	1140
70	6	− 45 5	65 9	20 4	21 3	5 9	35 4	268	388
80	6	− 39 8	75 3	35 5	36	3 5	21	139	264
90	6	− 35 4	84 7	49 3	49 7	2 5	15	89	212
100	6	− 31 8	94 2	62 4	62 7	2.0	12	64	188

* $f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.15 \times 50 \times 10^{-6}}} = 58.1$ cycles per second.

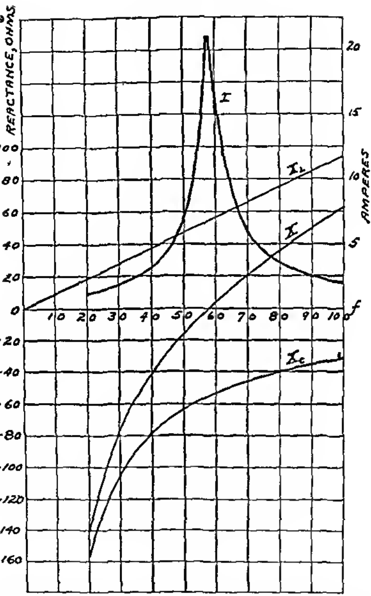

FIG 111 Resonance in a series circuit Current I inductive reactance X_L capacitive reactance X_c and total reactance X are plotted against frequency *f* Resonance occurs when *f* equals 58 1 cycles per second Current is a maximum and reactance zero at this frequency

RESONANCE IN PARALLEL CIRCUITS. A parallel circuit is said to be in resonance when the resultant susceptance of the circuit is zero. Let us consider a parallel circuit of three branches: the first, an ohmic resistance; the second, an inductance; and the third, a capacitance. The conductance of branch 1 is $1/R$; of branch 2, zero; and of branch 3, zero. The susceptance of branch 1 is zero; of branch 2, $1/X_L$; and of branch 3, $-1/X_C$ The total susceptance equals $1/X_L - 1/X_C$.
For resonance this must equal zero. Therefore,

$$\frac{1}{X_L} - \frac{1}{X_C} = 0 \quad \text{and} \quad X_L = X_C$$

Substituting for X_L and X_C, the expressions for inductive and capacitive reactance, we obtain

$$2\pi fL = \frac{1}{2\pi fC}$$

The frequency at which the parallel circuit will be in resonance is

$$f = \frac{1}{2\pi\sqrt{LC}},$$

the same frequency which will produce a condition of resonance in a series circuit containing the same inductance and capacitance.

Although the resonant frequency is the same for both series and parallel circuits, there are the following marked differences between the two circuits when in the resonant condition. First, the voltage drop is the same over all branches of the parallel circuit and never exceeds the impressed voltage. Second, the total current taken by the parallel circuit is a minimum at resonance, being zero if the total conductance of the circuit is also zero The current flowing in the branches, however, may be very high; and may, in fact, become excessively high. This circulating current represents an oscillation of electrical energy between the condenser and the coil. If, as will be shown in subsequent paragraphs, there is no resistance in the circuit to dissipate eventually the energy originally stored in the condenser, the oscillation once started will continue with undiminished amplitude forever.

Example. A parallel circuit consists of three branches. the first, containing a resistance of 800 ohms, the second, a capacitance of 50 microfarads; and the third, an inductance of 0.15 henry. The voltage impressed on the circuit is 550 volts, effective A Compute for various frequencies, 20 to 100 cycles per second: (a) the capacitive reactance of branch 2, X_C; (b) the inductive reactance of branch 3, X_L; (c) the current flowing through the resistance in branch 1, I_R, (d) the current flowing through the inductive reactance in branch 3, I_L; (e) the current flowing through the capacitive reactance in branch 2, I_C; (f) the total current taken by branch 2 and branch 3, $I_L + I_C$ (I_L and I_C are 180° out of phase, therefore, their sum is equal to $I_C - I_L$. If I_L is greater than I_C, the sign of the resultant current will be negative, showing that the resultant current is a lagging current), and (g) the total current I, the total current I being equal to the square root of the sum of the squares of I_R and $(I_C - I_L)$. Compute the resonant frequency for the circuit and then the quantities called for in (a) to (g) inclusive B. Compute the susceptance of each branch for the various frequencies considered in A and also the total susceptance of the circuit. C Plot the total current, the susceptance of each branch, and the total susceptance against frequency.

Solution

A

Frequency f	R	(a) $X_C=\frac{1}{2\pi fC}$	(b) $X_L=2\pi fL$	(c) $I_R=\frac{550}{R}$	(d) $I_C=550\times2\pi fC$	(e) $I_L=\frac{550}{2\pi fL}$	(f) I_C-I_L	(g) $I=\sqrt{I_R^2+(I_C-I_L)^2}$
20	800	159	18 8	0 69	3 46	29 3	−25 8	25 8+
30	800	106	28 2	0 69	5 19	19 5	−14 3	14 3+
40	800	79 5	37 7	0 69	6 91	14 6	− 7 7	7 7+
50	800	63 6	47 1	0 69	8 65	11 7	− 3 0	3 08
58 1*	800	54 7	54 7	0 69	10 05	10 05	0	0 69
60	800	53 0	56 5	0 69	10 40	9 8	0 6	0 92
70	800	45 5	65 9	0 69	12 10	8 4	3 7	3 76
80	800	39 8	75 3	0 69	13 80	7 3	6 5	6 54
90	800	35 4	84 7	0 69	15 50	6 5	9 0	9 03
100	800	31 8	94 2	0 69	17 30	5 8	11 5	11 52

$^*f=\frac{1}{2\pi\sqrt{LC}}=\frac{1}{2\pi\sqrt{0\ 15\times50\times10^{-6}}}=58\ 1$ cycles per second

B

f	*Susceptance*			
	Branch 1 $b=\frac{X}{R^2+X^2}$	Branch 2 $b_C=\frac{1}{X_C}$	Branch 3 $b_L=\frac{1}{X_L}$	Total $b=b+b_C+b_L$
20	0	− 0063	0532	+ 0469
30	0	− 0094	0354	+ 0260
40	0	− 0126	0265	+ 0139
50	0	− 0157	0212	+ 0055
58 1	0	− 0183	0183	0
60	0	− 0189	0177	− 0012
70	0	− 022	0152	− 0068
80	0	− 0252	0133	− 0119
90	0	− 0282	0118	− 0164
100	0	− 0314	0106	− 0208

C See Fig 112

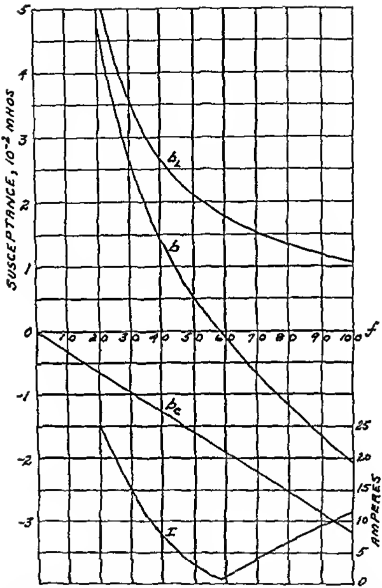

FIG 112 Resonance in a parallel circuit. Current I susceptance due to inductance b_L susceptance due to capacitance b_c and total susceptance b are plotted against frequency f Resonance occurs when f equals 58 1 cycles per second Current taken by the circuit is a minimum at this frequency, being 0 69 amperes This is the current taken by branch 1, which consists of an ohmic resistance of 800 ohms If this resistance were removed the current taken by the circuit would be zero at the resonant frequency Although no current during the steady state is being supplied to branches 2 and 3 a high circulative current flows through these branches

PART D. HIGH FREQUENCY CURRENTS

SECTION TWO. ALTERNATING CURRENTS OF HIGH FREQUENCY

GENERATION. As shown in the preceding section, the rotation of a coil in the magnetic field existing between two opposed magnetic poles, one a north pole and the other a south pole, results in the generation of an alternating electromotive force in the coil. A complete revolution of the coil generates one complete cycle. In order to generate 60 cycles per second, the speed of rotation would have to be 3600 revolutions per minute. Much higher frequencies than 60 cycles per second are required for electrosurgery and short wave diathermy in order to prevent neuromuscular effects Such frequencies must be of the order of 1,000,000 or more cycles per second. To generate frequencies of, let us assume, 600,000, 6,000,000, and 36,000,000 cycles per second, which are of the order of magnitude of the frequencies employed in medical and surgical diathermy, the coil of the generator already described would have to rotate at the tremendous speeds of 36,000,000, 360,000,000, and 2,160,000,000 r p m. respectively. Obviously the type of alternating current generator used for generating frequencies of the order of 60 cycles per second cannot be employed for generating the ultra high frequencies used in medicine for surgical applications and for the production of heat in living tissues.

OSCILLATING CIRCUIT. Figure 113 shows a simple circuit, comprising a battery, a condenser, a coil, a resistance, and a switch If the switch is thrown to position 1, the condenser will be charged to the potential of the battery. If the switch is now thrown to position 2, the condenser will discharge through the coil and the resistance, which are connected in series with it. The charging and discharging of a condenser may be likened, respectively, to the displacement and oscillation of a pendulum If there is absolutely no resistance to the motion of a pendulum, once started, it will continue to oscillate with undiminished amplitude forever. However, if there is resistance to motion of the pendulum, no matter how slight, the pendulum will finally come

to rest For during the oscillation of the pendulum the amplitude is continuously diminished, the frictional and air resistance to motion exerting a constant damping effect until, finally, the energy imparted to the pendulum originally will have been totally dissipated and the pendulum will have come to rest In this case the oscillation of the pendulum is said to be *damped,* and in the first case, when no resistance is exerted against the motion of the pendulum the oscillation is said to be *undamped* If the resistance is so great that the pendulum in its return swing does

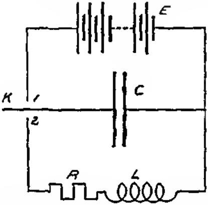

Fig 113 Simple Oscillating Circuit C is a condenser L the inductance and R the resistance of a coil E a source of voltage and K a key whereby the condenser may be charged and discharged

not pass beyond its position of static equilibrium the motion is *non oscillating*

If the ohmic resistance, which is the resistance to the flow of an electric current due to the composition and physical dimensions of a conductor, is zero—that is in Fig 113 $R = 0$ — the discharge of the condenser will be oscillatory and undamped The electric oscillation under this condition will continue forever But if resistance is present, the energy originally stored in the condenser will eventually be dissipated as heat in this resistance, and the electric oscillation consequently will die out Similarly to the frictional resistance in the mechanical analogue of the pendulum, the magnitude of the ohmic resistance of an electrical

oscillating circuit determines the degree to which the oscillatory current is damped. If the ohmic resistance exceeds a certain critical value, determined by the inductance and the capacitance of the oscillatory circuit, the discharge of the condenser will be non-oscillatory.

Referring to Fig. 113, when the condenser is connected to the battery, it will be charged; when connected to the inductance, it will be discharged. At the end of the discharge, the energy which had been stored in the condenser will be stored in the magnetic field set up by the flow of current through the coil. As soon as the potential of the condenser falls to zero, the current will begin to decrease and the lines of magnetic force about the coil to collapse. The collapse of the lines will induce a voltage in the coil, which will recharge the condenser. If there is no loss of electrical energy, due to ohmic resistance in the circuit, or to radiation of electromagnetic energy, the condenser will be re-charged to a potential equal in magnitude but opposite in polarity to that it had originally. The total energy of the charge will be the same as that originally stored in the condenser. The cycle of charging and discharging will be repeated indefinitely, resulting in an alternating current of undiminished amplitude.

However, if some of the energy originally stored in the condenser is dissipated on discharge as heat because of resistance in the circuit through which the condenser is discharging, and as electromagnetic radiation, the magnitude of the potential on recharge of the condenser will be less, each re-charge potential being less than the preceding. Theoretically, the electric oscillation never dies out regardless of the degree of damping. Practically, an oscillation is considered damped out when the amplitude has decreased to 1 per cent of its original value.

Figure 114 shows a damped electric oscillation, and also indicates the method employed in computing the instantaneous values of the current Fig. 115-a shows the condenser voltage and the current flow both plotted against ωt for the circuit considered in Fig. 114. In Fig. 115-b the energy stored in the condenser field and that stored in the magnetic field are plotted to show the relative

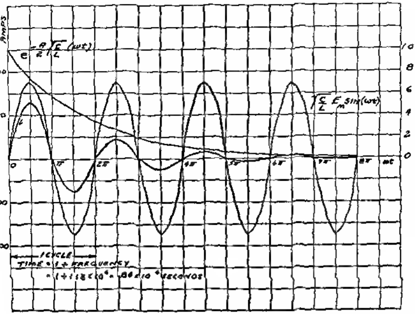

FIG. 114 Computed instantaneous current of a damped electric oscillation The capacitance C of the oscillatory circuit is 5000 micromicrofarads, the inductance L 4 microhenrys, the resistance R, 10 ohms, and E_M the initial potential of the condenser, 5000 volts The instantaneous current i for values of ωt from 0 to 8π radians was computed from the expression

$$i = \sqrt{\frac{C}{L}}\, E_M e^{-R/2\sqrt{C/L}(\omega t)} \sin(\omega t)$$

The current was plotted as positive, i e, the potential E_M to which the condenser is charged at the beginning of the discharge is considered negative The damping factor

$$\left(e^{-R/2\sqrt{C/L}(\omega t)}\right) \quad \text{and the factor} \quad \left(\sqrt{\frac{C}{L}}\, E_M \sin(\omega t)\right) \quad \text{are}$$

plotted separately against (ωt) The curve showing the variation in current flow with (ωt) is then obtained by multiplying these two curves instantaneous values of current being obtained by multiplying corresponding instantaneous values of the functions

$$\left(e^{-R/2\sqrt{C/L}(\omega t)}\right) \text{ and } \left(\sqrt{\frac{C}{L}}\, E_M \sin(\omega t)\right)$$

The frequency of the oscillation f equals $1/(2\pi\sqrt{LC})$ or 1 13 x 10^6 cycles per second The time for one complete cycle is 0 88 x 10^{-6} seconds

amount stored in each at successive instants during the oscillation shown in Fig 115-a *

* *Instantaneous Value of an Oscillating Current* The oscillations which occur in a simple circuit upon which no external alternating emf is applied are called the *free oscillations* of the circuit *Forced oscillations*, on the other hand, are those impressed on the circuit by an alternating emf from a source outside the circuit. When free oscillations are produced by the sudden discharge of a condenser, all of the energy which was stored in the condenser before discharge is lost from the circuit during the oscillations The potential difference of the condenser therefore, becomes lower and lower at every alternation of the current Since there is no emf applied from outside the circuit, the potential differences of condenser, resistance, and inductance must balance and their algebraic sum be zero That is

$$L\frac{di}{dt} + Ri + \int \frac{idt}{C} = 0$$

This is the same as the equation

$$L\frac{di}{dt} + Ri + \int \frac{idt}{C} = e$$

for simple alternating current theory, except that e the applied emf, is zero The solution that follows does not apply if the circuit contains a spark gap, for then the resistance R is not a constant

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The solution for the above equation for any circuit in which the resistance is constant and not extremely great, is

$$i = -\sqrt{\frac{C}{L}}\, E_M \epsilon^{-R/2\sqrt{C/L}(\omega t)} \sin(\omega t)$$

If C is in farads, L in henrys E_M in volts R in ohms and ωt in radians the instantaneous current i will be in amperes The negative sign indicates that the effect of the current is to decrease E_M i e, to release the charge on the condenser Whether the current is to be considered positive or negative during discharge depends upon the polarity of the charge on the condenser If the charge is considered positive, the current is then negative on discharge, if negative, the current is positive In either case the effect of the current flow is to decrease the charge on the condenser

Instantaneous Value of Condenser Voltage The relation between voltage across the condenser and the current in the circuit is

$$e_C = \int \frac{idt}{C}$$

Using this relation we obtain from the expression for current the approximate relation

$$e_C = E_M \epsilon^{-R/2\sqrt{C/L}(\omega t)} \cos(\omega t)$$

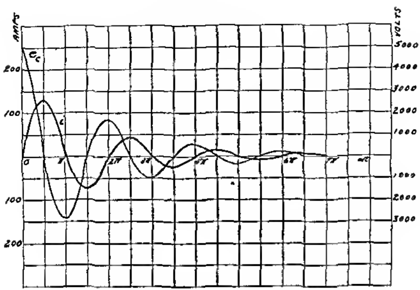

FIG 115-a. Condenser voltage e_c and current i plotted against ωt Condenser voltage was computed from the relation

$$e_C = E_M \epsilon^{-R/2\sqrt{C/L}(\omega t)} \cos(\omega t)$$

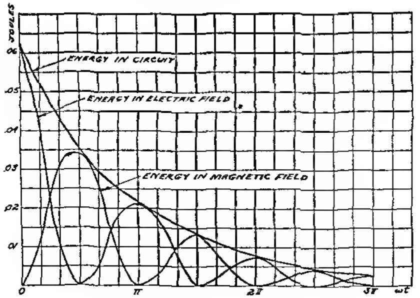

FIG 115-b See next page for description

Oscillation Frequency The oscillation frequency of an oscillatory circuit is a function of the inductance, the capacitance, and the resistance of that circuit In practically all high frequency circuits, the resistance is so small that its effect on the oscillation frequency is negligible in comparison with that of the inductance and the capacitance Therefore, for the purpose of this discussion it may be neglected Expressed quantitatively,

Frequency $= 1/(2\pi\sqrt{LC})$, approximately This equation gives frequency in cycles per second when L, the self inductance, is in henrys and C, the capacitance, is in farads

Effective Value of an Oscillatory Current The effective value of an alternating current is that value of a direct current which has an equivalent heating effect In the case of an undamped sinusoidal current, the effective value is 70 7 per cent of the maximum or *peak* value of the current The effective value of an undamped sinusoidal voltage is also 70 7 per cent of its peak value The effective value of an oscillatory current depends on

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Instantaneous Value of Energy in Condenser Since the instantaneous value of energy in the condenser w_C equals

$$\frac{Ce_C^2}{2}, \quad w_C = \frac{CE_M^2}{2} e^{-R\sqrt{C/L}\,t} \cos^2(\omega t) \text{ joules}$$

Instantaneous Value of Energy in Magnetic Field of Coil Since the instantaneous value of the energy stored in the magnetic field of the coil w_L equals $L\,i^2/2$

$$w_L = \frac{LI_M^2}{2} e^{-R\sqrt{C/L}\,t} \sin^2(\omega t) \text{ or}$$

$$w_L = \frac{CE_M^2}{2} e^{-R\sqrt{C/L}\,t} \sin^2(\omega t) \text{ joules}$$

FIG 115 b Total energy energy in electric field and energy in magnetic field plotted against ωt The energy at any instant in the electric field w_C equals in joules ½ C times the square of the instantaneous potential in volts of the condenser The instantaneous energy in the magnetic field w_L equals in joules ½ L times the square of the instantaneous current in amperes Actually the curve showing total energy is not a smooth exponential curve as shown in the figure but a wavy exponential curve This is due to the fact that the phase difference between current and emf is not exactly 90° The deviation from a 90° phase difference is caused by the resistance in the circuit

the number of complete oscillation trains generated per second Let N be the number of oscillatory discharges per second, C, the capacitance of the condenser in farads, R, the ohmic resistance, L, the inductance of the coil in henrys, and E_M, the maximum potential to which the condenser is charged The effective value of the current is then

$$I_{EFF} = E_M\sqrt{\frac{NC}{2R}}$$

The maximum value of the current, I_M, which is the initial maximum value, is given by the following equation

$$I_M = E_M\sqrt{\frac{C}{L}}\,\epsilon^{-R\pi/4\sqrt{C\,L}}\,*$$

To demonstrate the great disparity between the maximum or peak and the effective value of the current of a series of oscillatory

---

* *Effective and Maximum Value of an Oscillating Current* The total energy stored in a condenser of capacitance C farads when charged to a potential of E_M volts is ½ CE_M^2 joules If this condenser is charged and discharged N times per second the total energy stored in the condenser per second will be $NCE_M^2/2$ joules This must equal the total energy dissipated during the N discharges per second This energy will be converted into heat in the resistance of the discharge circuit The effective value of an alternating current is defined as that value of a direct current which has the same heating effect as the alternating current Therefore the effective current I_{EFF} amperes flowing for one second through the resistance R would have a heating effect of I_{EFF}^2 R joules per second This according to the definition of the effective current must be equal to the heating effect of the alternating current. We have already shown that $NCE_M^2/2$ joules are dissipated each second Hence

$$I_{EFF}^2R = \frac{NCE_M^2}{2}, \text{ or}$$

$$I_{EFF} = E_M\sqrt{\frac{NC}{2R}}$$

The maximum value of an oscillatory current can be obtained from the expression for the *instantaneous value of the current*

$$i = -\sqrt{\frac{C}{L}}\,E_M\epsilon^{-R/2\sqrt{C/L}(\omega t)}\sin(\omega t)$$

The instantaneous value is a maximum when ωt is approximately 90° or

discharges, let us compute these values for the current flowing in an oscillatory circuit, consisting of a condenser of 5000 micro-microfarads capacitance, a coil of 4 microhenrys inductance, and a resistance of 10 ohms. Let 5000 volts be the initial or maximum potential to which the condenser is charged at the beginning of each oscillatory discharge, and let there be 1000 complete oscillatory discharges per second.

$$I_{EFF} = E_M\sqrt{\frac{NC}{2R}} = \sqrt{\frac{1000 \times 5000 \times 10^{-12}}{2}} = 2.5 \text{ amperes.}$$

$$I_M = -E_M\sqrt{\frac{C}{L}}\,\epsilon^{-\pi R/4\sqrt{C/L}}$$

But $$E_M = 5000$$

and $$\sqrt{\frac{C}{L}} = \sqrt{\frac{5000 \times 10^{-12}}{4 \times 10^{-6}}} = \sqrt{1250 \times 10^{-6}}$$

$$= 10^{-3}\sqrt{1250} = 0\,0354$$

Also $$\frac{\pi R}{4} = \frac{3\,1416 \times 10}{4} = 7.854$$

Hence $$-\frac{\pi R}{4}\sqrt{\frac{C}{L}} = -7.854 \times 0.0354 = -0\,278$$

and $$\epsilon^{-R\pi/4\sqrt{C/L}} = \epsilon^{-0\,278}$$

$$\log \epsilon^{-0\,278} = -0\,278 \log \epsilon = -0.278 \times 0\,4343$$

$$= -0.1207 = 9\,8793 - 10$$

$$\epsilon^{-0\,278} = 0\,757.$$

Therefore $I_M = -5000 \times 0.0354 \times 0.757 = -134$ amperes.

$\pi/2$ radians Substituting $\pi/2$ for ωt in the above equation and solving for I_M we obtain

$$I_M = -\sqrt{\frac{C}{L}}\,E_M\epsilon^{-R/4\sqrt{C/L}(\pi/2)} \sin\frac{\pi}{2}\text{, or}$$

$$I_M = -E_M\sqrt{\frac{C}{L}}\,\epsilon^{-R\pi/4\sqrt{C/L}}.$$

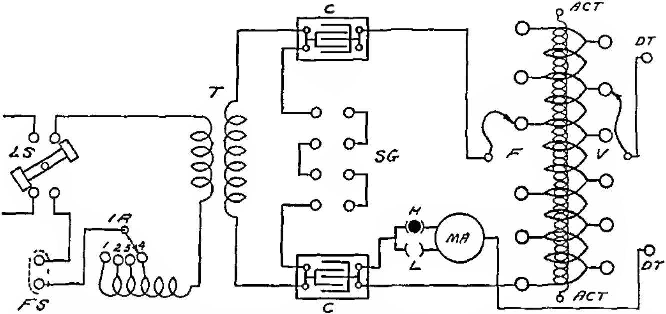


FIG 116 Schematic diagram of a typical conventional diathermy machine with a spark gap oscillating circuit Taps are provided on the inductance whereby the frequency and voltage may be varied F and V A secondary winding of relatively many turns is provided. By means of this winding a high voltage high frequency current is obtained for such applications as autocondensation Referring to the figure LS is line switch FS foot switch connection with jumper, IR intensity control T step-up transformer for a c line voltage, C condensers SG four spark gaps in series, MA high frequency milliammeter with high and low scale H and L F frequency taps V voltage taps, ACT autocondensation terminals and DT diathermy terminals

SPARK GAP OSCILLATOR (Conventional Diathermy Machine and Electrosurgical Unit) The electrical circuit of a typical diathermy machine of the spark gap type is represented schematically in Fig 116 It consists of a transformer, by means of which the voltage of the sixty cycle alternating current power supply is raised to several thousand volts, a reactance (intensity regulator) to control the current to the primary of the transformer, a series of spark gaps, condensers, and an oscillation transformer, the primary of which consists of a coil of a few turns of heavy wire and the secondary of which is a coil of a relatively great number of turns These elements with requisite meters and switches are connected as shown in Fig 116

From an inspection of this diagram, it will be noted that the condensers, the spark gaps, and the primary of the oscillation transformer constitute an oscillating circuit similar to the simple oscillating circuit already discussed The spark gap adds additional resistance to the circuit and, consequently, if the gap is wide the damping of the oscillation train will be greater because of the high resistance of the gap and the rapid dissipation of power in it in the form of heat Highly damped waves can be used for the heating of tissue and for the electrocoagulation and the electrodesiccation of tissue To produce cutting however, the current must consist of a succession of slightly damped waves In the design of spark gap oscillators for surgical application, care must be exercised to reduce resistance to a minimum in order to obtain the desired type of current for cutting The gaps of such machines are of minimum width In Fig 117 a typical spark gap circuit for electrosurgery is shown This unit has two circuits, one generating a current for coagulation and the other a current for cutting

Referring to Fig 116 provision is made whereby the oscillation transformer can be tapped at various points both on the input and output sides For ordinary conventional diathermy treatments, the oscillation transformer is used as an auto transformer For auto condensation, a treatment formerly extensively employed, and still somewhat in use, a secondary winding of a relatively large number of turns is employed The ammeter con

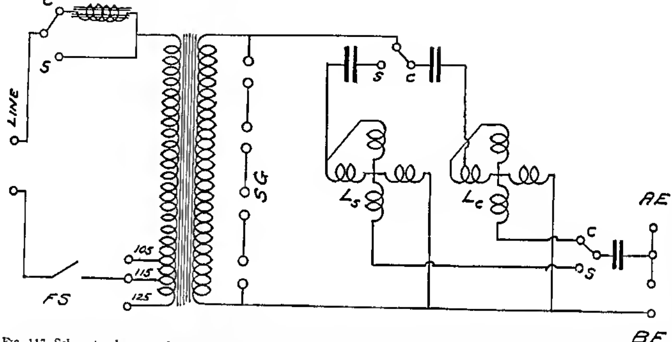


FIG 117 Schematic diagram of a generator of high frequency currents for electrosurgery The generator has two circuits, one designated by the letter S for the generation of a succession of slightly damped electric oscillations for the cutting of tissue and the other designated by the letter C for the generation of a succession of relatively highly damped oscillations for the coagulation or desiccation of tissue Referring to the figure FS is a foot switch SG spark gaps L_S vario coupler to control cutting current intensity L_C vario coupler to control coagulating current inteosity and AE and BE are re spectively active electrode terminals and body or dispersive electrode terminal

nected in series with the patient, as indicated in the diagram, is of the hot wire type and indicates the effective value of the high frequency current delivered to the patient

If the effective voltage applied to the oscillating circuit in Fig 116 is 5000 volts, 60 cycles, when 110 volts, 60 cycles are impressed on the primary of the transformer, and if the spark gaps are so adjusted that a potential of 7000 volts is required to break down the air gap, the condensers will be charged and discharged once every half cycle The period during which no current flows, or the interval between successive wave trains, is relatively very long in comparison with the time current is flowing For this setting of the spark gaps there are two condenser discharges per cycle of the impressed 60 cycle voltage or 120 per second This frequency of stimulation would result in pronounced neuromuscular response if applied to a patient and the diathermy generator would be said to produce a faradic effect Users of spark gap diathermy apparatus observed that if the gap was too wide, the patient would experience such an effect, and soon learned that by shortening the gap the effect could be eliminated By shortening the gap the voltage to break it down would be less, and so the number of wave trains delivered to the patient per second would be increased By proper adjustment of the gap and with a sufficiently high voltage impressed over the oscillating circuit, the number of oscillatory discharges per second can be raised sufficiently high to eliminate the so-called faradic effect The resulting succession of damped oscillation trains simulate in heating effect the continuous flow of a high frequency alternating current

The hot wire ammeter connected in series with the patient indicates the effective value of the high frequency current delivered to the patient and is that value of a direct current which has an equal heating effect The current read on the ammeter is much less than the peak value of the current received by the patient In a foregoing paragraph it was shown that the effective current value of a succession of damped high frequency oscillations (1000 per second) was only 2 5 amperes whereas the peak current value of each wave train was 134 amperes The more highly damped the oscillations are, the greater will be the ratio of the peak value of the current to its effective value

The frequency of the current generated by a spark gap oscillatőr is not single valued The range of frequencies generated and the harmonics present extend over a very wide hand, usually a megacycle or more in width.

VACUUM TUBE OSCILLATOR The simplest form of thermionic vacuum tube is the *diode*, having but two elements, a cathode and a plate. The cathode is heated by a battery provided for this purpose, which is designated an "A" battery. On becoming heated, the cathode—which may be a tungsten filament, a thoriated tungsten filament, or a surface coated with oxides and heated by means of a filament—emits electrons. These electrons flow to the plate when the plate is at a positive potential with respect to the cathode The diode obviously will conduct current in only one direction If a battery is connected with its negative terminal to the cathode and its positive terminal to the plate, the flow of current will be continuous; but if an alternating voltage is applied to the cathode and the plate, current will flow only when the plate is at a positive potential with respect to the cathode. In other words, current will flow only on the positive half cycles of the alternating voltage. The tube can thus he used as a rectifier.

The operation of the diode and of other thermionic vacuum tubes can best be understood from curves known as *tube characteristic curves*. In Fig 118 is shown the characteristic curve of a diode. This curve shows that with a fixed cathode temperature, the plate current increases with increase in plate voltage. Although the same total number of electrons are emitted per unit time for a fixed cathode temperature regardless of the plate voltage, the current flow increases at a lower rate for a given increment of plate voltage when the plate voltage is low than when it is high This is due to the fact that at low plate voltages only those electrons nearest the plate will be attracted to it. The electrons in the space near the cathode, being themselves negatively charged, will tend to repel the similarly-charged electrons leaving the cathode surface and cause them to return to the cathode. This effect is known as the *space charge effect* and is responsible for

the slow rate of increase of plate current with increase in plate voltage at low plate voltage values As the plate voltage is increased, more and more of the electrons emitted by the cathode are attracted to the plate. Finally the space charge effect is com-

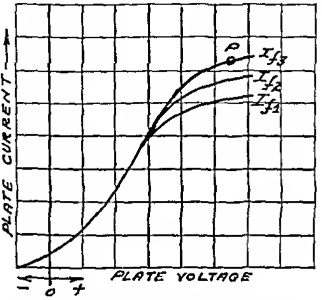


FIG 118 *Plate current plate voltage* characteristic of a diode for three filament temperatures, produced by three different filament currents, I_{f_1}, I_{f_2}, and I_{f_3} P indicates *saturation point* At this point, all electrons leaving the cathode reach the anode Further increase in current can be achieved only by increasing the temperature of the filament, thereby causing the emission of more electrons and a consequent increase in plate current A few of the electrons will be emitted from the cathode with sufficient velocity to reach the plate Hence, if the plate is connected back to the cathode, these electrons will flow back to the cathode through the external circuit, even though no external emf is impressed on the plate This small initial current occurs in all two-element tubes

pletely overcome and all the electrons reach the plate A further increase in plate voltage can produce no increase in plate current This point on the *plate current-plate voltage* characteristic is called the *saturation point* At this point increase in current flow can only be achieved by increasing the emission of electrons from

the cathode This can be done by increasing its temperature, the increase in temperature resulting in an increased emission of electrons

If a third element, called a control grid, is placed between the cathode and the plate, the space charge effect can be controlled Such a tube becomes a three element tube and is known as a *triode* A triode can be used for more purposes than rectification The grid is usually in the form of an open spiral or mesh of fine wire With the grid connected externally to the cathode and a source of direct current connected between the plate and the cathode with plate positive with respect to cathode, a continuous flow of electrons from cathode to plate through the openings of the grid will take place much as in the case of the diode However, if a source of variable voltage is now connected between the cathode and the grid, there will be a variation in the flow of electrons from the cathode to the plate as the grid voltage changes about a mean value When the voltage on the grid is made less negative i e more positive, with respect to the cathode, the space charge will be partially neutralized This will result in an increase in the number of electrons reaching the plate with a consequent increase in plate current When the grid is made more negative, i e, less positive, with respect to the cathode, the space charge will be reinforced and the plate current will decrease If a resistance or impedance is connected in the plate circuit, the variation in plate current will bring about a variation in voltage across this load The variation in voltage will be a magnification of the variation in grid voltage, in other words, amplification of the voltage variation on the grid has been obtained and the tube operates as an amplifier The amplifying power of a tube is given by its amplification factor μ (mu) This factor is the ratio of the plate voltage change required for a given change in plate current to the grid voltage change that will produce the same change in plate current

The operation of a triode as a *Class A* amplifier is represented graphically in Fig 119 The sloping curve shows the change in plate current for a fixed plate voltage as the grid voltage increases from a negative value sufficient to prevent flow of electrons to the

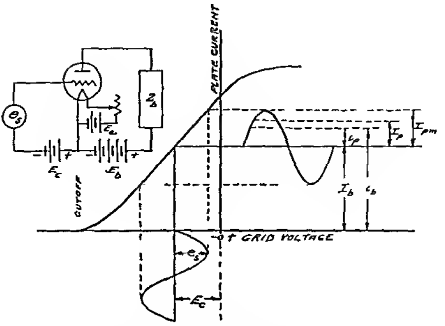


FIG 119 Basic circuit and operating characteristic of a Class A triode amplifier The voltage to be amplified is e_g It is impressed on the grid of the triode, which is maintained at a negative potential with respect to the filament of E_c volts known as the *bias voltage* This potential determines the operating point on the *plate current grid voltage* operating characteristic of the tube for the load impedance Z_b If this point is in the center of the practically linear portion of the characteristic the a-c component of the plate current will be practically similar to wave form to the voltage e_g The impedance of the load is Z_b and the voltage drop over the load due to the a c component of the plate current will be $i_p Z_b$ The voltage amplification is $A_v = i_p Z_b/e_g$

There is also a voltage drop over the load due to the direct current component of the plate current equal to $I_b R_b$ where R_b is the resistance of the load to direct current In the figure, i_p is the instantaneous value of the a c component of the total instantaneous current i_b I_b is the d c component of the total plate current, or, if the a c component is a sine wave or is symmetrical about the horizontal axis the average value of the total plate current. I_p *is the effective value of the a c component, and* I_{pm} *its maximum* value

plate through zero to a value slightly positive This curve is essentially a straight line over the middle section By proper choice of fixed grid voltage, or *bias*, a point of operation may be chosen

on the characteristic curve so that variation in plate current will be directly proportional to variation in grid voltage *

Amplifiers are frequently classified according to the operating conditions under which the tube works The classifications in general use are *Class A*, *Class AB*, *Class B*, and *Class C*

A *Class A* amplifier is one in which the plate current flows continuously throughout the cycle of alternating voltage applied to the grid Grid bias and alternating grid voltage are so selected that operation is confined to the linear portion of the E_g-I_p characteristic The amplifier shown in Figure 119 is such an amplifier A *Class A* amplifier produces no appreciable distortion of the waveform of the voltage impressed on the grid The power output, however, is low The d c component of the plate current is high, resulting in high plate dissipation of power

A *Class AB* amplifier is one in which the plate current flows for more than half but less than a complete electrical cycle Increased power is obtained but at the price of some distortion in the wave form

* There are two grid voltage plate current characteristics for the triode one that with constant plate voltage called the *static characteristic*, the other that with a variable plate voltage called the *dynamic characteristic*

In order to realize useful power from an amplifier the plate current which increases with increase in grid voltage and decreases with a decrease in that voltage must be conducted through an appropriate resistor or impedance Across this impedance power can be developed When the varying plate current flows through such a load the voltage drop over the load will vary The actual voltage over the plate of the tube will therefore vary being equal to the emf of the battery minus the voltage drop over the load As a result the E_g I_p characteristic will be continuously shifting even though the d c component of the plate current may be steady For an alternating voltage impressed on the grid there will be a constant change in the plate voltage

The static characteristic gives an indication of the performance of a tube for only one value of plate voltage If the plate voltage is changed the characteristic curve will shift

Hence the static characteristic cannot be used to plot the operation of a tube in an actual circuit The characteristic curve which takes into account the varying plate voltage that obtains during the operation of a tube is called the *dynamic characteristic* This operating characteristic shows actual plate current against grid voltage when there is an impedance in the plate circuit This curve depends upon the impedance of the load in the plate circuit as well as on the characteristics of the tube

A *Class B* amplifier is one in which the plate current flows for only one half of each cycle of the alternating grid voltage The biasing voltage is that value of the grid voltage for which the plate current is zero That is to say, the tube is operated at the *cutoff* Hence, on impressing an alternating voltage on the grid, plate current will flow only during the positive half cycle Further power output is gained but at marked distortion of wave form

A *Class C* amplifier is one in which the plate current flows for less than one half of the cycle of grid signal voltage In such an amplifier, the bias is greater than the cut off grid voltage High power output but great wave form distortion are the characteristics of such an amplifier Such an amplifier is strictly a power amplifier, whereas the *Class A* may be considered a voltage amplifier

When it is desired to amplify the magnitude of minute, varying voltages without distortion of the wave form, as in the study of heart potentials, a *Class A* amplifier must be used To obtain greater amplification than can be secured with a single tube, a series of stages is employed, with the output of one stage used as the input of the next In this manner, the desired amplification is obtained The thermionic vacuum tube amplifying electro cardiograph usually employs three stages, with an overall voltage amplification of about 800

Generation of Oscillations By virtue of the ability of a three element vacuum tube to amplify, the initial output of the tube is greater than its input Hence the tube can be arranged to provide its own input signal To enable the tube to generate a sustained electric oscillation, however, a sufficient portion of the output must be fed back into the input in the proper phase to reinforce the input energy The frequency of the oscillation is pre determined by the electrical constants of the circuit The *feed back,* as the feeding back of a portion of the output energy to the input circuit is termed may be accomplished in as many ways as it is possible to link the output circuit with the input circuit

Let us assume a typical tickler feedback oscillator circuit, Fig

120, for the purpose of explaining how oscillations are generated by a three electrode vacuum tube In this circuit energy from the plate circuit is fed from the so called tickler inductance L_2 to the grid inductance L_1 The frequency of oscillation f is determined chiefly by the values of the inductance L_1 and the capacitance C_1, f being equal in cycles per second to

$$\frac{1}{2\pi\sqrt{L_1 C_1}}$$

Whenever the rate of flow of current through a coil changes, the magnetic field about the coil will also change And, as we

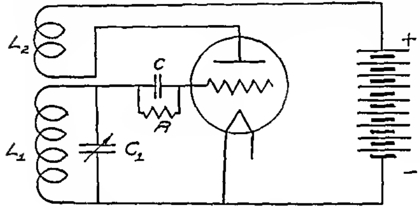


FIG 120 Typical tickler feedback oscillator circuit

have also learned in the preceding section, if the changing magnetic field cuts the turns of another coil, an emf will be induced in the second coil As the magnetic field expands with increase in current, the polarity of the voltage induced in the second coil will be in one direction And as it contracts with decrease in current, the voltage induced in the second coil will be in the opposite direction Also, if the current in the first coil is steady and unvarying, the magnetic field about that coil will be steady and unvarying When the magnetic field is in this static condition, no voltage will be induced in the second coil

Referring to Fig 120, when the filament, constituting the cathode of the tube, is energized, electrons will commence flowing

from the filament to the plate, resulting in a rising current flowing in the plate circuit. This current flows through the tickler coil L_2. As the filament heats up, more and more electrons are emitted, resulting in a rising current and an expanding magnetic field about the coil L_2, which is coupled inductively to the grid coil L_1. As a result of this expanding field, a voltage is induced in L_1. This voltage is impressed on the grid.

It will be noted from the figure that there is no C battery to provide a negative bias for the grid—that is to say, the grid bias is zero. As can be deduced from the characteristic curve of the triode, Fig 119, a tube so operated is highly sensitive to a change in grid potential, a given change in grid potential producing a much greater change in plate current when the potential of the grid is zero than when it is biased Hence, a minute voltage appearing on the grid will cause an immediate change in the magnitude of the current flowing in the plate circuit.

Let us assume that the initial voltage induced in L_1 and impressed on the grid is positive. The positive potential on the grid will exert a force of attraction on the electrons leaving the filament or cathode This force will accelerate the motion of the electrons towards the plate causing more electrons to reach the plate per unit time, thus increasing the plate current further The resulting expanding of the magnetic field about the tickler coil L_2 will induce a still larger positive voltage in the grid coil L_1. The increased positive potential of the grid will bring about a further increase in the plate current

The current in the plate circuit will continue to increase in this manner, the successive increases eventually tapering off until a final steady maximum value has been attained. The magnetic field about L_2 now ceases to expand and no longer induces a voltage in the grid coil L_1. Therefore, when the plate current reaches a final steady value, the grid loses its positive potential and returns to zero potential Since the grid no longer exerts an attractive force on the electrons leaving the cathode, fewer electrons reach the plate and the plate current begins to decrease As the plate current decreases, the field about L_2 contracts, inducing a negative voltage in L_1. The negative voltage, which is

now impressed on the grid repels the electrons leaving the cathode and thus reduces the plate current still further, thereby hastening the collapse of the field about L_2. As the collapse of the field is accelerated, the rate of cutting of the turns of the coil L_1 by the collapsing magnetic field is accelerated resulting in the induction of a still greater negative voltage in the grid coil. The resulting increase in the negative potential on the grid further reduces the plate current. This action continues until the field about the coil L_2 is completely collapsed and no longer induces a voltage in the grid coil L_1. The grid voltage thereupon returns to zero. Since it is now less negative than its previous value, the flow of electrons will increase with consequent increase in plate current. The cycle thereupon repeats itself.

What we have described may be termed the "initial action," for other actions are also taking place. Let us first consider what is taking place in the so called tank circuit L_1C_1. The voltage induced in the grid circuit by the feedback action will charge the condenser C_1. When the charging potential begins to decrease, the condenser C_1 will begin to discharge through the coil L_1. If the resistance of the discharge circuit is sufficiently small, an oscillatory discharge will take place. However, this oscillatory current would eventually die out if it were not for the fact that the grid circuit is replenished with energy once each cycle from the battery in the output circuit through the feedback coil L_2. The oscillations therefore continue unabated. The waveform as well as the frequency of the oscillation is governed by the grid circuit. The frequency depends upon the resonant frequency of the tank circuit. The waveform of the alternating current in a properly designed oscillator will approach that of a sine wave.

There is still to be considered the effect of the grid bias. This grid bias is effected by means of the resistance R, called the grid leak, and the grid condenser C. These two, which are connected in parallel with each other, are connected in series with the grid as shown in Fig. 120. These circuit elements function as follows to maintain a negative bias on the grid.

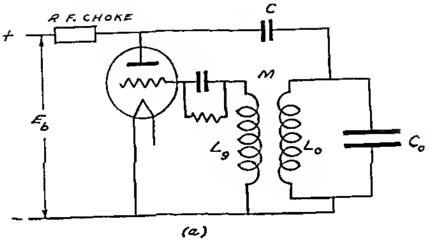
The capacitance of the condenser C is such as to provide a low impedance path for the excitation signal, thus permitting the

fluctuating excitation current to by-pass the high-resistance grid leak R. During positive variations, the grid draws current as does a diode. This direct current flows externally from the cathode, through L_1 and R, to the grid, and thence internally to the cathode. A voltage drop is thus developed across the resistance R, the end of R nearest the grid being less positive than the other end of the resistor. The grid is therefore negative with respect to the cathode by an amount equal to the potential drop over the resistor R.

The voltage developed across the resistor R, during the time current flows, charges the condenser C. During the negative phase of the excitation signal when no grid current flows, the condenser will tend to discharge through the resistance R. But if the capacitance of C and the resistance of R are properly chosen, the rate of discharge will be comparatively slow The higher the capacitance of the condenser, the greater the charge it can hold, and consequently the greater the time that will be required to discharge it. Furthermore, the higher the grid-leak resistance, the slower will be the rate of discharge.

In an oscillator, values of C and R are usually so chosen that the time-constant, as we refer to the rate of discharge of the condenser-grid leak combination, is made fairly long in comparison with the time of one cycle of the excitation signal. Hence, the potential of the condenser C does not drop appreciably during a complete cycle of the excitation signal. During the positive phase of the succeeding excitation signal, the condenser potential will be restored, and thus an appreciably constant negative potential with respect to the cathode is maintained on the grid

Since the oscillator is self-excited, any increase or decrease in plate current is immediately reflected in an increase or decrease in the excitation voltage which is induced in the grid circuit by the action of the feedback coil L_2. This is followed by an increase or decrease in grid bias. Such change in grid bias will oppose any further change of plate current in the same direction. In this way, a rise in the average value of the plate current is offset in a few cycles by a rise in grid bias which reduces the plate current. If the value of C should be too high, however, the time-constant may



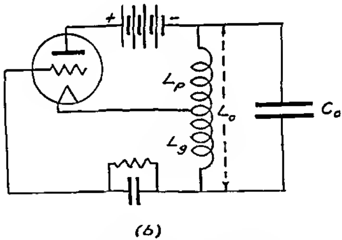
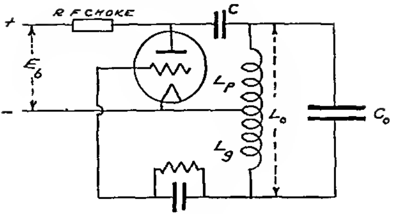
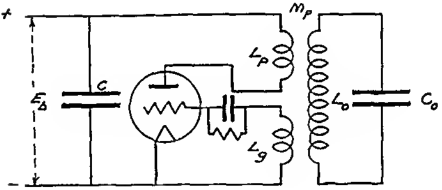


FIG 121 Typical oscillating circuits (a) Tuned plate circuit, shunt feed (b) Hartley circuit, series feed

become so great that the grid will become insensitive to a sudden change in the average plate current Under such conditions the tube may oscillate intermittently, the starting and stopping rate depending upon the time-constant of the C-R combination.



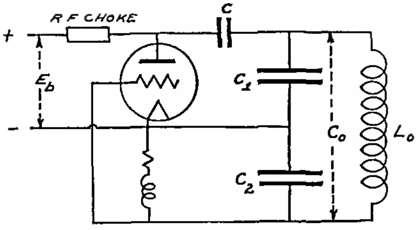
(c)



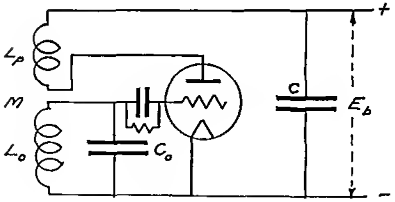
(d)

FIG 121 Typical oscillating circuits (c) Hartley circuit, shunt feed (d) Meissner circuit

As has been shown in the foregoing paragraphs, when the plate *voltage is applied to the tube, the initial surge of current in the* plate coil induces a current in the grid coil resulting in the setting up of oscillations in the grid circuit The amplitude of oscillation builds up until equilibrium is established between the losses in the circuit and the ability of the tube and battery to supply the required power. Use may be made of the oscillating current in the



(e)



(f)

FIG 121 Typical oscillating circuits (e) **Colpitts circuit** (f) Tuned grid circuit

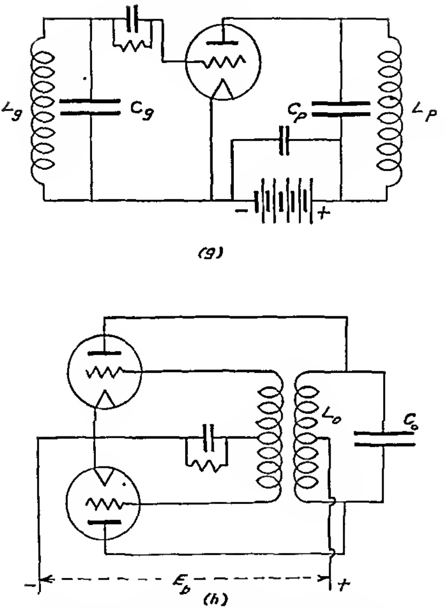
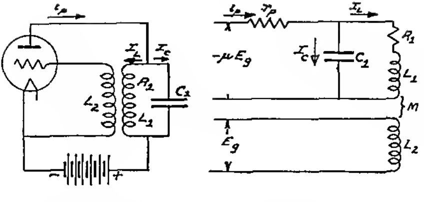


FIG 121 Typical oscillating circuits (g) Tuned grid, tuned plate circuit (h) Push pull circuit.



(a) (b)

FIG 122 (a) Tuned-plate oscillator (b) Its equivalent circuit i_p is the current flowing in the plate circuit which is equal to the vector sum of I_L and I_C the currents flowing through the plate inductance and capacitance respectively E_g is the emf impressed on the grid This is 180° out of phase with respect to the voltage impressed on the plate and is equivalent in effect so far as the flow of current in the plate circuit is concerned to a plate voltage of $-\mu E_g$ volts M is the mutual inductance of the grid and the plate inductances R_1 represents the resistance of the plate inductance and the resistance of the load assuming it a pure resistance load.

plate coil by coupling a load to it Typical oscillating circuits are shown in Fig 121 *

* *Mathematical Analysis of Tuned plate Oscillator* An approximate treatment of a tuned plate oscillator from which some general principles applicable to all vacuum tube oscillators may be deduced follows In Fig 122 is shown a tuned plate oscillator and its equivalent circuit By assuming steady state conditions and applying Kirchhoff s laws to the equivalent circuit the following equations can be obtained

(1) $$i_p = I_L + I_C$$

(2) $$-\mu E_g = i_p r_p + I_L(R_1 + j\omega L_1)$$

(3) $$\frac{I_C}{\omega C} = I_L(R_1 + j\omega L_1)$$

(4 $$E_g = j\omega M I_L$$

Substituting (1) and (4) in (2)

(5) $$j\mu\omega M I_L = (I_L + I_C)r_p + I_L(R_1 + j\omega L_1)$$

Substituting the value of I_C from (3) in (5)

(6) $$j\mu\omega M I_L = j\omega C I_L(R + j\omega L_1)r_p + I_L(R_1 + r_p + j\omega L_1)$$

Crystal Controlled Oscillator. The frequency generated by a vacuum tube oscillator of the type that has been described will vary with change in load A short wave diathermy machine is subjected to widely varying loads and hence its frequency will vary, more with some types of circuits than with others During

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from which

(7) $$I_L[(R_1 + r_p - \omega^2 L_1 C_1 r_p) + j\omega(L_1 + C_1 R_1 r_p - \mu M)] = 0$$

For the left hand member of (7) to be equal to zero, each of the two terms *within the brackets must be equal to zero Setting of the j terms equal to* zero, we obtain

(8) $$M = \frac{L_1 + C_1 R_1 r_p}{\mu}$$

which gives the *minimum* value that M *must have in order that the circuit* may oscillate.

Setting the real term of (7) equal to zero we get

(9) $$\omega = \sqrt{\frac{R_1 + r_p}{L_1 C_1 r_p}} = \omega_0 \sqrt{1 + \frac{R_1}{r_p}}$$

where $\omega_0 = 1/\sqrt{L_1 C_1}$ From equation (9) it is seen that the frequency of oscillation is affected to some extent by the resistance of the load (R_1 being made up of the resistance of the coil and that of the load) as well as by the *plate resistance of the tube r_p Hence a change in the load resistance or any* changes in the operating conditions of the tube which cause a variation in r_p such as variations in the plate supply voltage or filament temperature, will *cause changes in the frequency of oscillation.*

In Fig 123 is shown the vector diagram of the alternating components of the currents and voltages of the tuned plate oscillator The grid voltage E_g and the resultant voltage μE_g acting in the plate circuit are 180 degrees out of phase which fact accounts for the negative sign of μE_g in (2) The output voltage across the *load* is E_o, which is equal to $-\mu E_g$ minus the internal drop $i_p r_p$ within the tube The current I_L lags E_o by an angle θ, which depends upon the ratio of ωL_1 to R_1 of the coil The excitation voltage E_g must lag behind I_L by 90 degrees, hence the sign of M must be negative in order to produce this condition. The current I_C through C_1 leads E_o by almost 90 degrees depending upon the losses in this portion of the tank circuit The plate current i_p is the vector sum of I_L and I_C Actually i_p is badly distorted Hence the vector representing i_p in Fig 123 must be regarded as the fundamental component of the plate current.

From (8) it is readily seen that the condition for oscillation can be destroyed by overloading the oscillator Too close coupling resulting in an increase in the resistance referred back into the tank circuit will increase R_1. Increase in R_1 requires an increase in M, or a proportionate decrease in L_1,

the operation of such apparatus an electromagnetic field is radiated into space having the same frequency as the oscillating current generated by the short wave apparatus, fluctuating with fluctuations in the frequency of the oscillatory current The operation of a short wave machine therefore may interfere with

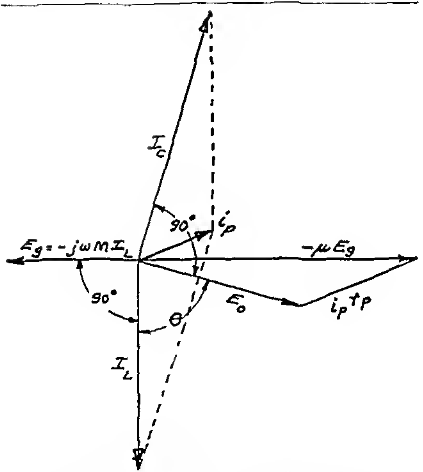

FIG 123 Vector diagram of the alternating components of the currents and voltages of the tuned plate oscillator shown in Figure 122

C_1 or r_p in order that the generator do not cease to oscillate In the use of short wave diathermy generators the technic to be employed should be such that disturbance of the conditions for oscillation be not brought about By following the instructions prepared by the manufacturer such interference with proper functioning of the apparatus will be avoided

short wave radio communication. To prevent such interference one of two things can be done. First, the generator may be screened. Such screening must include the patient also, for the patient otherwise would serve as a radiator of electromagnetic waves In addition, wave filters mnst be placed in the input circuit to prevent feedback into the power line; otherwise the power line would serve as a radiator. Furtbermore, telephone and lighting circuits which enter the screened room must be equipped with wave traps to prevent such circuits from acting as antennas To screen a room properly requires great care—good bonding of the screening at all junctions, electrically symmetrical grounding to prevent the screened cubicle from acting as a radiator, the use of highly conductive screening material and if of mesb, all crossings of wires must be soldered, etc. A great deal of work has been done by the Canadian Government in devising screening methods for sbort wave diatbermy apparatus. The following publications of the Department of Marine, Radio Branch, Canadian Government, should be consulted by those desiring detailed information and suggestions on shielding of short wave diatbermy apparatus:

S 11—10—25: Suppression of Radio Inductive Interference from Electro-Medical Apparatus

S 11—10—34: Suppression of Radio Inductive Interference from Electro-Medical Apparatus

Second, definite frequencies may be allocated for short wave diathermy apparatus. If sbort wave diathermy apparatus alone use these frequencies, no interference with communications will of course result A reasonable deviation, plus or minus, from the allocated frequency must be allowed. In the Federal specification for short wave diathermy apparatus, adopted by the Director of Procurement for the use of all the departments and establishments of the United States Government, the frequencies 13 660 and 40 980 megacycles are called for, depending upon the type of application the machine is to be used for. The machine must maintain a frequency stability of plus or minus 0.05 per cent for all applications in an ambient temperature range from 10° to 40°C. With such a machine no screening is of course required,

since the field radiated by it will not interfere with communication channels of other frequencies.

The frequency of a vacuum tube oscillator can be controlled by various electro-mechanical arrangements. The most extensively employed means of controlling frequency is the quartz crystal Quartz crystals have the property known as *piezoelectric effect.* When such a crystal is subjected to a mechanical stress, a potential difference will appear over the faces of the crystal, and, conversely, when a voltage is applied across the faces, the crystal will change in dimension. If the applied pressure is alternating, the potential will be alternating; if the applied potential is alternating, the crystal will be set into mechanical vibration.

The crystal is sandwiched between two metal mounting plates Since this amounts to two conductive plates separated by an excellent insulator, having a dielectric constant of about 4.5, it might be thought that a quartz crystal so mounted would act as a condenser. However, this is not necessarily true, for, depending upon the frequency employed, the crystal may act as a resistance, an inductance, or a capacitance. The equivalent circuit of a crystal is a resistance, an inductance, and a capacitance connected in series, and this series circuit connected in parallel with a second capacitance. It must not be concluded, however, that an arrangement of coils, condensers, and resistances could be substituted for a crystal The ratio of reactance to resistance in a crystal may be more than 100 times that obtainable with an electrical circuit Hence, the resonance peak of a quartz crystal is many times more sharp than could be achieved by the best coils and condensers. This property, together with its piezoelectric effect, makes the quartz crystal so effective in stabilizing the frequency of an oscillator.

A typical crystal-controlled oscillating circuit is shown in Fig 124 It is essentially a tuned-plate, tuned-grid circuit, except that a quartz crystal is substituted for the coil and condenser in the grid circuit.

If the circuit is placed in operation by applying voltage to the plate circuit, an instantaneous change in plate current takes place. There results a transmission of a voltage surge to the grid by

way of the internal grid-to-plate capacitance of the vacuum tube. This voltage surge is also applied to the crystal. As a result the crystal is mechanically deformed. Upon the cessation of the surge, the crystal returns to its former shape. In doing so, it develops a potential across its faces. This potential is applied to the grid and is amplified by the tube. Part of this amplified voltage is fed back to the grid and thence to the crystal. Thus the generation of sustained electrical oscillations starts.

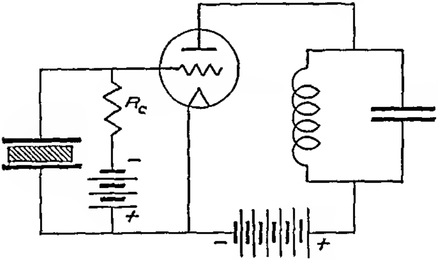

FIG 124 Typical crystal controlled oscillating circuit

The crystal has alternately a voltage applied to it which causes it to change its shape, and then the crystal, in resuming its original shape, generates a voltage which is impressed on the grid The grid is therefore subjected to a voltage having a frequency corresponding to the natural resonant frequency of the quartz crystal.

From the foregoing it is evident that the crystal functions as a tank circuit, during the first half of the cycle storing energy in mechanical form, and during the second half releasing it in electrical form The rate of storage and release depends upon the natural resonant frequency of the crystal. This rate determines

the frequency of the oscillations generated by the tube The plate circuit may in fact be considerably detuned from the resonant frequency of the crystal without affecting materially the frequency of the oscillations, which will remain that of the quartz crystal

FIG. 125 *Inductotherm Model C* Crystal controlled short wave diathermy generator for induction field application Frequency of oscillation 13 660 mc Tolerance ± 0 05 per cent (*Courtesy General Electric X Ray Corporation*)

The higher the frequency, the thinner the quartz crystal must be. Hence to obtain high frequency currents of appreciable power, such as are required for short wave diathermy, frequency multiplying and power amplifying circuits must be used. Crystal-controlled oscillators for medical use which meet the requirements established by the United States Army have been constructed. Fig. 125 shows such a unit designed for operation at 13 660 megacycles. The induction field method of applying the high frequency energy is utilized It has an output of more than 200 watts, sufficient for all applications including fever therapy.

Typical Circuits Used for Short Wave Diathermy Generators. In Fig 121 were shown the typical basic vacuum tube oscillator circuits. In the design of circuits for short wave diathermy application, one of these basic circuits is employed with such modification as the use to which the apparatus is to be put requires. The number of oscillator tubes used is one or two Some machines operate with raw a c. impressed on the plate circuits, others with rectified a.c., and still others with rectified a c. filtered to various degrees In Fig 126 is shown the schematic diagram of a one-tube oscillator using raw a c. on the plate, designed for induction heating. This particular machine has proved highly satisfactory for the full range of diathermy application including fever therapy As will be shown in a subsequent paragraph, its maximum useful output approaches the maximum available output of the device That is to say, its thermogenic efficiency is high. The oscillation frequency of the machine ranges between 10 and 15 megacycles, depending upon the number of turns and the configuration of the treatment cable This cable, as can be seen from the diagram in Fig 126, constitutes the inductance of the tank circuit and hence is effective in determining the oscillation frequency of the generator. The circuit is the Colpitts type, as can be seen by comparing it with the typical basic oscillating circuits in Fig. 121. Such a circuit has a high electrical efficiency, for the resistance of the tank inductance and the cable applicator is a minimum, since the cable also serves as the tank inductance.

In Fig. 127 is shown the schematic diagram of a two-tube

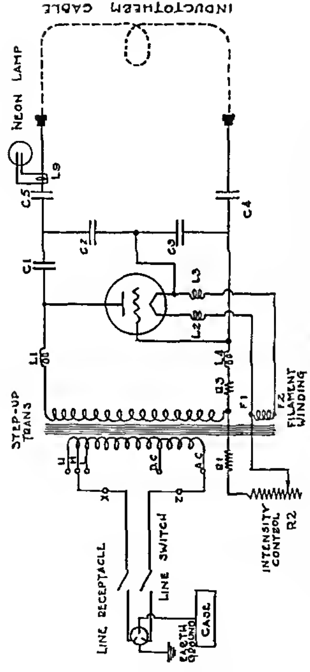

Fig 126 Schematic diagram of the *Inductotherm, Model B* One-tube short wave diathermy generator for induction heating (*Courtesy General Electric X Ray Corporation*)

Hartley push-pull circuit designed for induction heating Raw a c. is also impressed on the plate circuit of this oscillator. This unit, too, is a highly satisfactory circuit. Its thermogenic efficiency, however, is not so high as the unit whose circuit is shown in Fig 126, because of the additional power losses in tank inductance

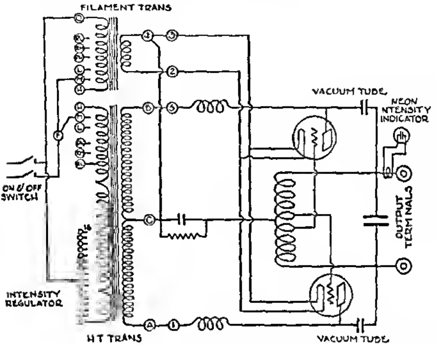

FIG. 127 Schematic diagram of the *Inductotherm, Model A* Two tube short wave diathermy generator for induction field application (*Courtesy General Electric X-Ray Corporation*)

and cable The oscillation frequency of this apparatus is approximately 12 megacycles Since the treatment cable is not part of the tank circuit, change in its configuration does not affect the oscillation frequency to the same extent as in the unit described in the previous paragraph

Fig 128 shows the schematic diagram of a two-tube circuit having three tank circuits, any one of which may be switched into the circuit, depending upon the frequency desired The frequency to be generated, and hence the tank circuit to be used, is deter-

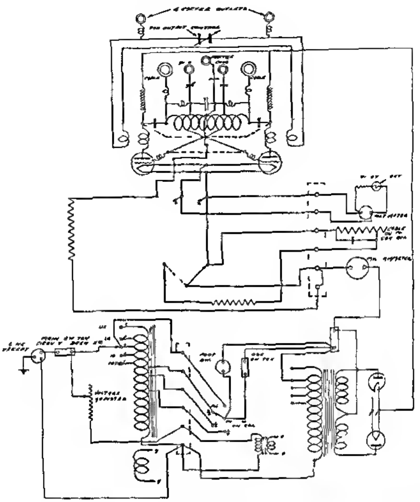

FIG 128 Schematic diagram of a triple frequency short wave diathermy generator 50 mc for air spaced electrode application, 12 mc for induction field application, and 3 75 mc for electrosurgery (*Courtesy Burdick Corporation*)

mined by the manner in which the high frequency energy is to be applied to the patient For induction heating a lower frequency is used, of the order of 10 to 15 megacycles For condenser field application, a frequency of 40 to 50 megacycles is used The reasons for using frequencies of such order of magnitude for these

applications will be discussed in subsequent paragraphs. This particular machine is designed to generate a frequency of 50 megacycles for air-spaced electrode application, 12 megacycles for induction heating, and 3.75 megacycles for electrosurgery. The use of the considerably lower frequency for electrosurgery minimizes the leakage of current from the scalpel or coagulation electrode to the hand of the operator and thence to the ground through the operator's body, which is capacitively grounded. The capacitive reactance of the capacitor formed by the operator's hand and the conductor of the electrode as plates and the insulation of the electrode as the dielectric decreases with increase in frequency. Therefore, by using a lower frequency but with the current at the same effective voltage, the leakage is materially reduced. The basic circuit employed in the machine is the tuned-plate, tuned-grid, push-pull oscillator circuit, as can be shown by comparing it with the basic oscillating circuits given in Fig. 121.

Effect of Frequency on Characteristics of Circuit Elements. We have already discussed in Section One, dealing with alternating current circuit theory, the increase in opposition to the flow of current that develops in an inductance as the frequency of the current is increased. When the frequency of the impressed voltage is zero, i.e., when the voltage has a constant unvarying value, the only opposition a coil exerts against the flow of electric current is its ohmic resistance. As the frequency increases, the impedance, as the coil opposition is called, increases. In the case of a pure resistance, the opposition remains constant for increase in frequency through the range concerned with in power and lighting circuits, being the ohmic resistance of the resistor. But where the frequency is increased to the high values we are concerned with in short wave diathermy, the resistance increases. In the case of a capacitance the opposition decreases, until at high frequencies a capacitance that permits negligible current at 60 cycles per second to flow will readily pass currents of high effective value. In the following paragraphs we shall discuss the effect frequency has on the impedance of the basic circuit elements, which are *resistance, inductance,* and *capacitance.*

Resistance. It may be shown that the distribution of direct current in a system of conductors, or over the cross section of a single conductor, is such that the production of heat is a minimum. This results in a uniform distribution of the current over the cross section of a single conductor of uniform configuration and material. But when alternating current flows in a conductor, the current tends to flow more in the outer portions of the conductor than in the center. The higher the frequency, the greater does the distribution of current depart from the direct current distribution. At high frequencies the current flows in a thin layer at the surface of a metallic conductor; hence the term *skin effect* to describe this effect. As a result of this effect, the effective or current carrying area of a given metallic conductor may be but a fraction of the actual cross section Hence, the resistance of a conductor to the flow of a high frequency current may be many times that of its direct current resistance.

The ratio of resistance at any frequency to the direct current resistance can be calculated for certain simple forms of conductors For the purpose of this discussion, which is to compare the effect of frequency on the resistance of highly conductive conductors with that on conductors of lower conductivity, comparable to tissue, the consideration of a conductor in the form of a straight cylinder will suffice The relationship in which we are most interested is not the absolute resistance at various frequencies, but rather the ratio of resistance at a given frequency to that for direct current. The following equation is taken from *Bureau of Standards Circular No 74, Radio Instruments and Measurements:*

$$x = \pi d\sqrt{\frac{2\mu f}{\rho}}\cdot\sqrt{\frac{1}{1000}}$$

in which d is the diameter in centimeters of the conductor; μ the magnetic permeability of the material; f the frequency; and ρ the volume resistivity in microhm-cms. After computing the value of x, the ratio of the resistance at the frequency f to the resistance for direct current (R/R_o) can be determined from Table 36, taken from the Bureau of Standards publication already referred to.

TABLE 36

RATIO OF HIGH FREQUENCY RESISTANCE TO THE DIRECT CURRENT RESISTANCE

x	$\frac{R}{R_o}$	Diff	x	$\frac{R}{R_o}$	Diff	x	$\frac{R}{R_o}$	Diff
0	1 0000	0 0003	5 2	2 114	0 070	14 0	5 209	0 117
0 5	1 0003	0004	5 4	2 184	070	14 5	5 386	176
6	1 0007	0005	5 6	2 254	070	15 0	5 562	353
7	1 0012	0009	5 8	2 324	070	16 0	5 915	353
8	1 0021	0013	6 0	2 394	069	17 0	6 268	353
9	1 0034	0018	6 2	2 463	070	18 0	6 621	353
1 0	1 005	003	6 4	2 533	070	19 0	6 974	354
1 1	1 008	003	6 6	2 603	070	20 0	7 328	353
1 2	1 011	004	6 8	2 673	070	21 0	7 681	353
1 3	1 015	005	7 0	2 743	070	22 0	8 034	353
1 4	1 020	006	7 2	2 813	071	23 0	8 387	354
1 5	1 026	007	7 4	2 884	070	24 0	8 741	353
1 6	1 033	009	7 6	2 954	070	25 0	9 094	353
1 7	1 042	010	7 8	3 024	070	26 0	9 447	70
1 8	1 052	012	8 0	3 094	071	28 0	10 15	71
1 9	1 064	014	8 2	3 165	070	30 0	10 86	71
2 0	1 078	033	8 4	3 235	071	32 0	11 57	70
2 2	1 111	041	8 6	3 306	071	34 0	12 27	71
2 4	1 152	049	8 8	3 376	070	36 0	12 98	71
2 6	1 201	056	9 0	3 446	071	38 0	13 69	71
2 8	1 256	062	9 2	3 517	070	40 0	14 40	70
3 0	1 318	067	9 4	3 587	071	42 0	15 10	71
3 2	1 385	071	9 6	3 658	070	44 0	15 81	71
3 4	1 456	073	9 8	3 728	071	46 0	16 52	70
3 6	1 529	074	10 0	3 799	176	48 0	17 22	71
3 8	1 603	075	10 5	3 975	176	50 0	17 93	3 54
4 0	1 678	074	11 0	4 151	176	60 0	21 47	3 53
4 2	1 752	074	11 5	4 327	177	70 0	25 00	3 54
4 4	1 826	073	12 0	4 504	176	80 0	28 54	3 53
4 6	1 899	072	12 5	4 680	176	90 0	32 07	3 54
4 8	1 971	072	13 0	4 856	177	100 0	35 61	—
5 0	2 043	071	13 5	5 033	176	∞	∞	

A consideration of the foregoing equation shows that the skin effect is greater for materials of high conductivity than for those of low conductivity Furthermore, conductors of magnetic material show an exaggerated increase of resistance with increase of frequency

Let us now assume three conductors: the first of copper, the second of lead, and the third of a non-magnetic material having the conductivity of isotonic saline solution (.85 grams NaCl per 100 grams solution) Let the diameter be the same for all, 1 cm The magnetic permeability, we will assume, is unity for each of the conductors The resistivities of these materials appear in Table 37 as given in the *Handbook of Chemistry and Physics, 23rd Edition,* and the *International Critical Tables.*

For values of x greater than 7, the following relation between the ratio R/R_o and x holds to within less than 1 per cent, the error being less the greater the value of x:

$$R/R_o = x/2.828 + 0.25$$

Since Table 36 does not extend far enough to include all values for x computed for the conductors of copper and lead which were assumed in the discussion, the foregoing equation was used to compute R/R_o for those values of x which are greater than 100

In Table 38 are tabulated the computed values of x and the corresponding values of the ratio R/R_o for the three conductors for frequencies from 0 (direct current) to 50,000,000 cycles per second.

In Fig 130, R/R_o is plotted against f for the three conductors.

TABLE 37

Material	Temperature	Resistivity	Authority
Copper—commercial annealed	20° C	1 7241 microhm-cms	Handbk Chem & Physics
Lead	20° C	22 0	Handbk Chem & Physics
Isotonic Saline	20° C	73×10^6	Int Crit Tables*

* *Conductivity of Aqueous Solutions of Sodium Chloride* Since aqueous solutions of sodium chloride are so often used as a lead in determining the electrical characteristics of short wave diathermy apparatus, the following data from the *International Critical Tables* on the conductivity of such solutions may be useful to investigators in this field and for that reason are given here for ready reference

In the following table, the concentration c is given in milliformula weight per liter,

CONDUCTIVITY OF AQUEOUS SOLUTIONS OF SODIUM CHLORIDE (FROM INT CRIT TABLES)

Concentration		Conductivity at									
		0° C		18° C		25° C		50° C		100° C	
c	Grams Per 100 cc Solution	λ	k	λ	k	λ	k	λ	k	λ	k
0.1	0.0005845	—	—	97.82	$.098\times10^{-4}$	—	—	—	—	—	—
0.2	0.001169	—	—	97.31	195	—	—	—	—	—	—
0.5	0.0029225	—	—	104.95	555	125	625×10^{-4}	—	—	345.9	1.7745×10^{-4}
1.0	0.005845	65.8	0.658×10^{-4}	106.27	1.063	124.1	1.241	193.3	1.933×10^{-4}	352.5	3.525
2.0	0.01169	65.2	1.304	105.31	2.11	123	2.46	193	3.86	348.5	6.97
5.0	0.029225	64.2	3.210	103.54	5.18	120.8	6.04	190	9.50	341.9	17.10
10.0	0.05845	63.2	6.32	101.72	10.17	118.6	11.86	183	18.3	335	33.5
20.0	0.1169	61.7	12.34	99.4	19.88	115.8	23.16	179.9	35.98	325.4	65.1
50.0	0.29225	59.5	29.73	95.51	47.76	111	55.5	170.8	85.40	309.7	154.9
70.0	0.40915	58.7	41.09	—	—	109	76.3	167.1	116.97	303.2	212.2
100.0	0.5845	57.7	57.70	91.82	91.82	106.6	106.6	165.4	165.4	295.6	295.6
200.0	1.169	55.6	111.2	87.53	175.1	101.5	203	155.6	311.2	287.9	575.8
500.0	2.9225	51.8	259	80.76	403.8	93.3	366.6	141.9	709.5	274.4	1372
[illegible]	4.0915	49.9	340	—	—	—	—	—	—	263.6	1845
						—	—	—	—	247.3	2473

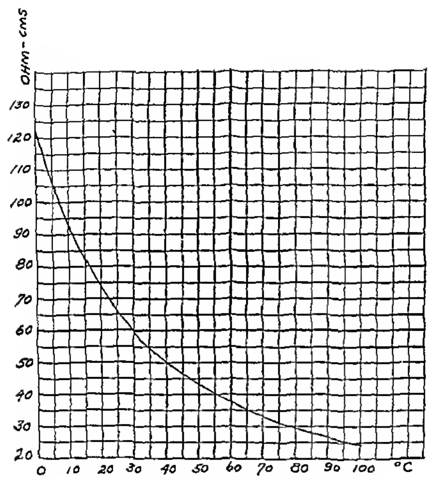

FIG 129 Resistivity in ohm cms of isotonic saline solution at various temperatures

that is in milligram-equivalents per liter The molecular weight of sodium chloride equals the atomic weight of sodium (22 997) plus the atomic weight of chlorine (35 457) or 58 454 The concentration of a gram-equivalent solution of sodium chloride would be that of a solution containing 58 454 grams of sodium chloride per liter In milligram equivalents or in milliformula weight per liter its concentration is 58454 milligrams per liter *Such a solution is said to contain 1 mole of solute per liter of solvent and is referred to as a one-mole solution*

The molecular conductivity of a solution is defined as the ratio of the volume conductivity in reciprocal ohm-cms to the number of moles of solute per unit volume of solution The symbol for molecular conductivity is λ and if the concentration c is in

TABLE 38

f	Copper		Lead		Isotonic Saline	
	x	R/R_0	x	R/R_0	x	R/R_0
0	0 0	1 00	0 0	1 00	0 0	1 00006⁻
100	1 068	1 007	298	1 00018	1 645$\times10^{-4}$	—
1,000	3 35	1 511	942	1 0042	5 2$\times10^{-4}$	—
10,000	10 68	4 038	2 98	1 3118	16 45$\times10^{-4}$	—
100,000	33 5	12 1	9 42	3 594	52$\times10^{-4}$	—
1,000,000	106 8	38	29 8	10 789	164 5$\times10^{-4}$	—
5,000,000	239 0	84 8	67 6	24 15	0367	—
10,000,000	335 0	118 6	94 2	33 56	0520	—
20,000,000	477 0	169	132 5	47	0735	—
30,000,000	585 0	207	163 3	58	0902	1 00006⁻
40,000,000	675 0	239	188 5	66 8	104	1 00006⁺
50,000,000	754 0	267	210 5	74 7	1165	1 00007

From Fig 130 it is readily seen that, whereas at frequencies

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milligram-equivalents per liter and the volume conductivity k is in ohm^{-1} cm^{-1}, the relationship between λ, c and k can be expressed by the following equation

$$\lambda = 10^6 \frac{k}{c}$$

whence $$k = c\lambda \times 10^{-6}\ \text{ohm}^{-1}\ \text{cm}^{-1}$$

From the data in the foregoing table, a series of curves can be plotted showing the variation of conductivity with concentration for temperatures of 0° C, 18° C, 50° C, and *100° C The concentration of isotonic saline solution is 0 85 grams per 100* grams of solution or 8 50 grams per liter The molecular weight of sodium chloride is 58 454 A solution of NaCl having a concentration of 1 milliformula weight per liter contains therefore, 0 05845 grams NaCl per liter The concentration of isotonic saline in milli formula weights per liter is 8 50/ 05845 or 145 4

From the series of curves referred to in the foregoing paragraph, the conductivity of isotonic saline at various temperatures can be readily determined In the following table, corresponding values of temperature, molecular conductivity, volume conductivity, and resistivity are recorded In Fig 129, the resistivity of isotonic saline is plotted against the temperature of the solution From the curve showing the variation of resistivity with temperature, it is found that at 20° C the resistivity of isotonic saline is 73 ohm-cms, or 73 000 000 microhm-cms

SPECIFIC CONDUCTIVITY AND RESISTIVITY OF ISOTONIC SALINE AT VARIOUS TEMPERATURES

Temperature	*Conductivity*		Resistivity in Ohm-cms
	$\lambda = 10^6 k/c$	$k = c\lambda \times 10^{-6}$	
0 C	56 7	83 0$\times10^{-4}$	120 5
18	89 7	131 5	76 1
25	104 0	152 3	65 6
50	160 0	234	42 7
100	290 5	426	23 4

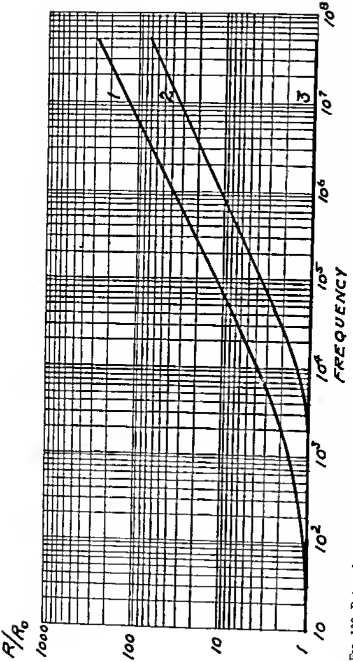

FIG 130 Ratio of resistance at various frequencies, from 10 cycles to 10^8 cycles per second, to d c resistance (1) Copper conductor, 1 cm in diameter (2) Lead conductor, 1 cm in diameter (3) Conductor of material having resistivity of isotonic saline also 1 cm in diameter

of the order used in short wave diathermy, 1,000,000 to 50,000,000 cycles per second, the resistance of metallic conductors becomes many times the direct current resistance, the resistance of a conductor having a conductivity comparable to that of isotonic saline remains practically the same as the direct current resistance throughout this range of frequencies Hence one must not erroneously assume that, because of the so called skin effect, the distribution of current flow in a homogeneous conductor of low conductivity is such that only the outermost layers of the conductor carry the current So far as tissue is concerned, the skin effect can be neglected The distribution of current flow in such materials is affected only by the impedances of the various possible pathways and not by the so called skin effect, which as we have shown has such a pronounced influence on the distribution of current flow in metallic conductors The term *skin effect*, as used by electrical engineers, has no anatomical connotation, and hence when it is said that *skin effect* is negligible in non magnetic conductors having a conductivity comparable to tissue, it must not be assumed that excessive heating of skin cannot occur with high frequency currents and fields To this latter effect the term *skin effect* is frequently applied by physicians Such excessive heating of the skin is due to improper methods of introducing the high frequency energy into tissue and to faulty technic in applying electrodes In subsequent sections the precautions to be taken in order to obviate excessive superficial heating will be discussed in detail

Inductance A circuit, such as a coil, which possesses inductance must necessarily possess resistance In addition to resistance, the coil has capacitance Therefore, in considering the effect of frequency on the electrical characteristics of a coil, we will consider the effect of frequency on each of these quantities which together make up the impedance of the coil

The same principle that governs the distribution of current in an isolated conductor also determines the distribution of current in the conductors of a coil, that is, the current density is greatest in those parts of each coil conductor which are linked with the least magnetic flux The skin effect in coils is, however

much more complex and much greater in magnitude than in isolated conductors, because each turn of the coil produces magnetic flux that influences the distribution of current in adjacent turns Hence, the exact theoretical investigation of the increase in coil resistance, as the frequency is increased, becomes exceedingly difficult. Any such treatment requires consideration of the gradient of the magnetic field in which the various turns lie, the effect of the mutual induction of all the other turns on the turn being examined, effect of the space necessary between turns for insulation, etc. Even after many simplifications have been made, the solutions usually involve coefficients expressible only by infinite series, which furthermore frequently converge slowly, thus necessitating the computation and summation of a tediously great number of terms Luedemann has proposed the following relation for single-layer solenoids of solid wire:

$$R/R_o = 1 + \alpha \sqrt{f} + \beta f^2$$

in which R is high frequency resistance, R_o is direct current resistance, f is frequency, and α and β are constants which must be determined experimentally at frequencies much lower than the natural frequency of the coil

The high frequency resistance of a coil may be hundreds of times greater than its direct current resistance.

Because of the change of current distribution within a conductor with increase in frequency, the self-inductance of a coil tends to decrease as the frequency increases. There is no appreciable change in the mutual inductance. The change in self-inductance is, however, very small, although it decreases somewhat more rapidly in the case of a coil than it does in the case of the same length of wire laid out straight. Since the self-inductance changes but slightly, we will consider the self-inductance constant in this discussion. The distributed capacitance of the coil, however, changes rather markedly with increase in frequency, and at radio frequencies such capacitance becomes of great importance An appreciation of the effect of frequency on the distributed capacitance of a coil, and hence on the electrical characteristics of a coil, is of value in applying the induction field properly for

the treatment of patients, as will be pointed out in subsequent paragraphs

The distributed capacitance of a coil is made up of the capacitances between the turns of the coil In Fig 131 is shown the equivalent circuit of a coil with a self inductance of L henrys, a resistance R, and a distributed capacitance of C_o farads The capacitance C_o is that capacitance which, when considered connected in parallel with an inductance of L henrys and a resistance of R ohms, will have the same effect on the electrical characteris-

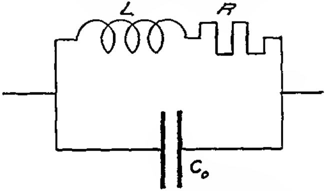

FIG 131 Equivalent circuit of a coil with an inductance of L henrys a resistance of R ohms and a distributed capacitance of C_o farads

tics of the coil as the various capacitances between the turns of the coil Hence the coil and its distributed capacitance form a parallel circuit as shown in the figure already referred to Let R be the resistance of the coil for the frequency f Then, if R_a is the apparent resistance of the coil and L_a the apparent inductance, it may be shown that

$$R_a = \frac{R}{\omega^2 C_o^2 R^2 + (1 - \omega^2 L C_o)^2}$$

$$L_a = \frac{L(1 - \omega^2 L C_o) - C_o R^2}{\omega^2 C_o^2 R^2 + (1 - \omega^2 L C_o)^2}$$

The terms $\omega^2 C_o R^2$ and $C_o R^2$ are very small and negligible, except

when the frequency approaches that value for which the quantity $(1 - \omega^2LC_o)$ equals zero The frequency at which the quantity $(1 - \omega^2LC_o)$ equals zero is the frequency at which the coil would oscillate by itself—that is, it is the resonant frequency of a circuit containing the inductance L and the capacitance C_o For other frequencies we may write

$$R_a = \frac{R}{(1 - \omega^2LC_o)^2}$$

$$L_a = \frac{L}{(1 - \omega^2LC_o)}.$$

From a consideration of the foregoing expression for the apparent inductance of a coil, it is readily seen that, although the distributed capacitance of a coil may be very low, the value of ω^2LC_o may become greater than 1 if the frequency is sufficiently increased When such occurs, L_a becomes negative. This means that the coil is behaving as a condenser, and to tune the coil to resonance under such conditions a series inductance would be required

Not only by increasing the frequency can the term ω^2LC_o be made greater than 1 and thus the apparent inductance be made negative, resulting in the coil behaving as a condenser, but also by increasing the distributed capacitance of the coil or its inductance The total distributed capacitance of the coil will be increased by decreasing the space between turns, and the inductance by increasing the number of turns.

By forming the conductor from a large number of small insulated wires connected in parallel at their ends, but insulated from each other throughout the rest of their length and thoroughly interwoven, the skin effect can be minimized. If the stranding is properly done, each conductor will, on the average, link with the same number of lines of magnetic force as every other conductor, and the current will divide evenly between the strands If each strand is small, it will have relatively little skin effect over its cross section, and the current density will be approximately that for direct current. Under such conditions the high

frequency resistance will be approximately the direct current resistance of the coil. If there is no change in the current distribution as the frequency is increased, the self-inductance, too, should remain constant, remaining that for direct current.

In order to acquire an appreciation of the effect of frequency on the functioning of a coil in a high frequency circuit, and thereby acquire suggestions as to the proper manner in which an inductance cable should be applied in giving short wave diathermy treatment in order to assure its functioning as an inductance, let us assume a cable and make approximate computations of its apparent inductance as the frequency is increased. It must of course be understood that precise computations cannot be made, but the approximate determination of the electrical characteristics of the inductance applicator will provide information which will serve as a guide in making efficient use of such an applicator in actual treatment.

Let us assume a cable properly stranded and with the strands so interwoven that there is no appreciable change in resistance with increase in frequency, that is, a cable constructed in the manner described in a foregoing paragraph. Let us assume the diameter of the conductor to be 1 cm. and the diameter of the coil 20 cm. Furthermore, to simplify the problem, let the coil be unloaded and the turns uninsulated. The dielectric between the turns will then be air with a dielectric constant of one and a

TABLE 39

INDUCTANCE AND DISTRIBUTED CAPACITANCE OF VARIOUS COILS
(Dia. of Conductor 1 cm., Dia. of Coils 20 cms.)

Coil	Turns	Pitch	L	C_o	Coil	Turns	Pitch	L	C_o
		cms					cms		
1	2	1.5	1.265μh	18.2μμf	9	4	4	3.48μh	8.5μμf
2	2	2	1.15	13.2	10	4	5	3.16	7.62
3	2	3	1.00	9.9	11	6	1.5	11.37	18.2
4	2	4	.88	8.5	12	6	2	10.35	13.2
5	2	5	.79	7.62	13	6	3	8.95	9.9
6	4	1.5	5.05	18.2	14	6	4	7.82	8.5
7	4	2	4.62	13.2	15	6	5	7.1	7.62
8	4	3	3.92	9.9					

magnetic permeability likewise of unity The core of the coil, being of air, will also have a permeability of one In Table 39 the inductance and distributed capacitance of a coil made of the conductor we have assumed are given for various turns and various pitches *

* *Inductance of a Single Layer Coil* An expression giving the approximate value of the inductance of a single layer solenoid follows

$$\frac{0\ 03948 N^2 R^2}{l} K \text{ microhenrys}$$

where N = the number of turns of the winding, R = the radius of the coil in cms measured from the axis to the center of any wire, l = the length of the coil in cms, and K = a function whose value depends on the ratio $2R/l$ In the following table are values of K for various values of 2 R/l as calculated by Nagaoka

2R/l	K	2R/l	K	2R/l	K	2R/l	K
0 00	1 000	0 50	0 818	1 00	0 688	4 00	0 365
05	979	55	803	1 10	667	4 50	341
10	959	60	789	1 20	648	5 00	320
15	939	65	775	1 40	611	6 00	285
20	920	70	761	1 60	580	7 00	258
25	902	75	748	1 80	551	8 00	237
30	884	80	735	2 00	526	9 00	219
35	867	85	723	2 50	472	10 00	203
40	850	90	711	3 00	429		
45	834	95	700	3 50	394		

Applying the foregoing expression to Coil 1 having 2 turns a radius of 10 cm, a winding pitch of 1 5 cms and consequently a length of 4 cms we find the coil to have an inductance

$$L = (0\ 03948 \times 2 \times 2 \times 10 \times 10)/4 \times 0\ 32 = 1\ 265 \text{ microhenrys}$$

The inductances of the rest of the coils tabulated in Table 39 were computed similarly

Distributed Capacitance of a Coil From the experimental determinations of Palermo (A J Palermo *Distributed Capacity of Single Layer Coils* Proc I R.E, 22 897 1934) the following expression for the distributed capacitance of short single layer coils has been developed

$$C_o = \frac{\pi D}{3\ 6 \cosh^{-1}(s/d)} \text{ micro-microfarads}$$

where s = pitch of winding in cms d = bare wire diameter in cms. and D = winding diameter in cms The term $cosh^{-1}$ (s/d) means *the angle whose hyperbolic cosine is s divided by d* After s/d has been computed the value

Let us now compute the apparent inductance of the various coils for values of frequency from 1,000,000 to 100,000,000 cycles per second from the expressions for this quantity given earlier in this discussion of the influence of frequency on inductance In Table 40 are given the computed values

The resonant or natural frequency of an inductance coil is that frequency for which $(1 - \omega^2 LC_o)$ equals zero Equating this expression to zero and solving for frequency, we obtain

$$\omega = 2\pi f = \frac{1}{\sqrt{LC_o}}$$

$$f = \frac{1}{2\pi\sqrt{LC_o}} .$$

In Table 41 the resonant frequencies of the various coils considered in this discussion are tabulated

---

of this term is obtained from a table of hyperbolic functions

The important parameters in the coil capacitance are the diameters of the winding and the ratio of the pitch of the winding to the diameter of the bare wire. The capacitance is practically independent of the number of turns

The insulation on the conductor and the form on which the coil is wound, in short wave diathermy this form is of living tissue increase the distributed capacitance of the coil by reason of their mass and dielectric coefficient Insulation of the cable conductor used for diathermy application will absorb energy through dielectric hysteresis Hence such insulation should be selected with the view of reducing such losses Furthermore, the insulation should be of such character as not to absorb moisture Likewise and for the reasons given the drum or disk enclosing a permanently wound coil of bare conductor must be of a material of as low a dielectric loss as is feasible and must be impervious to moisture Properly constructed disk and drum applicators for induction heating by short wave diathermy are designed with a view to reducing losses and assuring an applicator of high efficiency

Applying the expression for distributed capacitance to Coil 1, with $D = 20$ cm $d = 1$ cm, and $s = 1\ 5$ cm we find its distributed capacitance to be

$$C_o = \frac{3\ 1416 \times 20}{3\ 6 \cosh^{-1}(1.5/1)} \mu\mu f$$
$$= \frac{3\ 1416 \times 20}{3\ 6 \times 0\ 9624} = 18\ 2\ \mu\mu f$$

The distributed capacitances of the rest of the coils tabulated in Table 39 were found in the same manner

TABLE 40

APPARENT INDUCTANCE OF VARIOUS COILS AT DIFFERENT FREQUENCIES

Coil \ f	Apparent Inductance in Microhenrys											
	1×10^6	5×10^6	10×10^6	20×10^6	30×10^6	40×10^6	50×10^6	60×10^6	70×10^6	80×10^6	90×10^6	100×10^6
1	1.27	1.3	1.39	1.98	7.05	−2.16	−1.01	−0.56	−0.37	−0.26	−0.20	−0.16
2	1.15	1.17	1.22	1.32	2.5	28.8	−2.3	−1.0	−0.6	−0.4	−0.3	−0.23
3	1.00	1.01	1.04	1.19	1.54	2.73	5.00	−2.44	−1.1	−0.66	−0.46	−0.34
4	0.87	0.88	0.90	0.99	1.18	1.64	3.22	−17.4	−2.02	−1.00	−0.64	−0.45
5	0.69	0.70	0.71	0.75	0.85	1.03	1.44	−2.76	−69.0	−2.09	−1.02	−0.64
6	5.05	5.55	7.9	−11.2	−2.22	−1.05	−0.63	−0.42	−0.30	−0.23	−0.18	−0.14
7	4.62	4.93	6.09	154.0	−3.95	−1.62	−0.93	−0.6	−0.43	−0.32	−0.25	−0.2
8	3.92	4.09	4.6	10.1	−10.3	−2.68	−1.39	−0.87	−0.61	−0.44	−0.34	−0.27
9	3.48	3.59	3.96	6.06	−58.0	−40.0	−1.81	−1.09	−0.74	−0.54	−0.41	−0.33
10	3.16	3.22	3.51	5.1	22.5	6.08	−2.3	−1.31	−0.87	−0.62	−0.47	−0.37
11	11.37	14.4	63.3	−5.02	−1.79	−0.94	−0.59	−0.40	−0.29	−0.2	−0.17	−0.14
12	10.35	12.03	28.8	−8.92	−2.68	−1.35	−0.83	−0.56	−0.41	−0.31	−0.24	−0.16
13	8.95	9.82	13.75	−22.4	−4.15	−1.95	−1.16	−0.77	−0.56	−0.42	−0.33	−0.26
14	7.82	8.4	10.55	−157	−5.72	−2.44	−1.41	−0.93	−0.66	−0.5	−0.39	−0.31
15	7.10	7.55	9.0	47.3	−7.72	−2.93	−1.64	−1.07	−0.76	−0.56	−0.44	−0.35

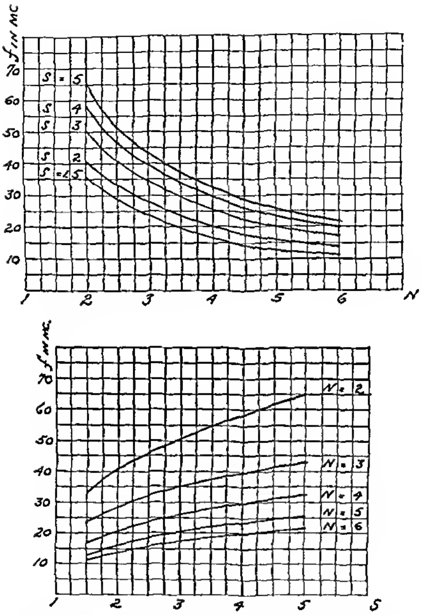

FIG 132 (a) Resonant frequency of coils with different pitches S plotted against number of turns N Mean diameter of coil 20 cm. Diameter of copper conductor 1 cm (b) *Resonant frequency of coils with different numbers of turns N plotted against pitch S i e distance between turns center to center in cms*

2 inches or 5 cm. (the conductnr being 1 cm. in diameter and the diameter of the coil being 20 cms., values which correspond to the diameter of conductnr and diameter of coil frequently employed in actual treatment) has a resonant frequency of about 43,000,000 cycles per second, well above the frequency of 15,000,000 which we assumed was to be used in the coil. Sbould 4 turns be employed, the resonant frequency would be 32,500,000 cycles per second, still well above 15,000,000 cycles per second. To obtain the same ratin of resonant frequency to operating frequency as in the case nf 3 turns, the spacing must be increased. From Fig. 132-b it is seen that a horizontal line drawn through the ordinate 43,500,000 cycles per second will intersect the curve for a coil of 4 turns, if that curve is extrapolated, at a point having an abscissa of approximately *7.5 cms.* nr about 3 inches.

Tbe foregoing rather extensive discussion of the effect of frequency on the functioning nf a coil such as is used for induction heating in short wave diathermy, was for the purpose of establisbing certain simple principles of tecbnic in the mind of the physician and operator of such apparatus. Consideration of these principles will aid in administering successful and satisfactory treatment.

In a following discussion pertaining to the beating of electrolytes by bigb frequency currents and fields, the effect of increasing the frequency on the heating characteristics of the induction field for a given coil will be experimentally demonstrated.

Capacitance. The construction nf a capacitor and the effect of the insulating material or dielectric separating the conducting surfaces on the capacitance bas already been discussed. In the case of a perfect condenser, the current leads the impressed emf 90 degrees, as was sbown in the preceding section on alternating current circuit theory. However, it is impossible to construct a perfect condenser that absorbs no energy whatsoever.

The dielectrics used in condensers are solids, liquids, and gases. The power loss in solid dielectric condensers may be grouped under the following heads:

1. Loss due to conduction nf current through the dielectric or leakage of current nver its surface; sucb loss is appreciable when the insulation resistance of the dielectric is low.

2. Actual conductor resistance loss in leads, connections, and the plates themselves.

3. Loss due to dielectric absorption or hysteresis; such loss *is occasioned by the work done per unit time by the impressed* emf in overcoming the attractive forces between the displaced electron and the positively charged particles tending to hold the electron in a position of static equilibrium. With an alternating emf, the displacement of the electron is first in one direction and then in the other.

4. Corona loss due to discharge from plate edges; this loss is important at high voltages.

The air condenser approaches a perfect condenser. In such a condenser, if constructed of rugged plates of negligible resistance, all the losses in the condenser proper are negligible except at voltages high enough to give corona loss.

In the case of a condenser having a dielectric of low resistance and consequently permitting considerable flow of current from plate to plate through the dielectric on the application of potential, the apparent or measured capacitance will vary with the frequency of the impressed emf Such a condenser is known as a *leaky condenser*, and can be represented electrically by a capacitance connected in parallel with a resistance. The capacitance at any frequency of such a parallel circuit, which is the apparent capacitance of the condenser at that frequency, can be shown to be

$$C = C_o\left(1 + \frac{10^{12}}{R^2\omega^2C_o^2}\right)$$

in which C_o is the geometric capacitance in microfarads and R the leakage resistance in ohms

It is evident that the apparent capacitance of a leaky condenser decreases very rapidly as the frequency is increased and becomes equal to the geometric capacitance at infinite frequency, the geometric capacitance of the condenser being that computed from the dimensions of the condenser and the dielectric constant of its dielectric.

METHODS OF APPLICATION OF HIGH FREQUENCY CURRENTS AND FIELDS IN MEDICINE. ***Conventional Diathermy.*** By this term

is meant the application for medical purposes of the bigh frequency current generated by the spark gap type of oscillator In view of the fact that such generators are being rapidly supplanted by vacuum tube oscillators generating frequencies of much bigher values, no extended discussion of the methods of application will be attempted. Briefly, application of the energy is made by means of uninsulated electrodes of thin, pliable, metallic alloy, applied directly to the skin of the patient. Care must of course be taken that contact is uniformly good to assure uniform distribution of current. The technic of applying such electrodes in the actual treatment of patients will be discussed in a subsequent section

Short Wave Diathermy. The medical use of the bigber frequencies as generated by a vacuum tube oscillator for the development of beat in living tissues, is known as short wave diathermy.

Associated with the flow of electric current in an electric circuit there exist about that circuit both an electric and a magnetic field. Any change in the current will produce a corresponding change in the electromagnetic field, but at a later time. The speed at which the change in the field is propagated is the speed of light —300,000,000 meters per second. If the current change is periodic and alternating in character, similar periodic and alternating changes in the magnetic and electric fields will be propagated into space. At any point in space, the direction and amplitude of the fields will vary periodically in direction and intensity. In one second there will be as many complete cycles of cbange as there are complete cycles of change per second in the current giving rise to tbe field The wavelength, or distance between two points in the disturbance in the same pbase (i e, the distance between successive crests, or troughs, etc.), will be 300,000,000 meters divided by the frequency. The wavelength of the wave radiated by a generator baving a frequency of 10,000,000 cps is 30 meters; 20,000,000 cps, 15 meters, 50,000,000 cps, 6 meters The use of the term *short wave diathermy* was undoubtedly suggested by the fact that relatively short radio waves are radiated into space by the high frequency current flowing in the circuits of the oscillator. Tbe term is somewhat misleading, since it suggests

that a patient is treated by a radiation field, whereas the fact is that the patient is definitely made part of a high frequency circuit coupled relatively closely to the tank circuit of the oscillator.

Since higher frequencies are employed than in conventional diathermy, the electrodes may be brought away from the skin with an intervening space of air or some other non-conductive material. The resulting capacitance connected between each electrode and the patient introduces a capacitive reactance. As the frequency of the current is increased, the opposition offered by a capacitance decreases Hence, considerable thickness of insulating material may be interposed between the metallic electrodes and the skin of a patient and still have sufficient flow of current, provided the frequency is sufficiently high. Such pad electrodes, however, produce chiefly superficial heating. Tests conducted under the auspices of the Council on Physical Therapy have definitely established that pad electrodes are relatively ineffective methods of application so far as depth heating is concerned Since the only valid reason for the use of high frequency currents is to heat the living tissues of a patient without overheating the superficial tissues, the Council has most correctly refused to declare acceptable the use of pad electrodes for short wave diathermy.

Cuff electrodes, similar in construction to pad electrodes, have been used satisfactorily for applying high frequency currents to extremities Such electrodes, however, are far from being universally applicable to all parts of the body.

The third and most important method of applying short wave diathermy by means of the condenser field, consists of the use of air-spaced electrodes of metal provided with protective cages or containers of insulating material such as bakelite and glass The distance between the electrode and the patient's skin can be varied. The effect of varying spacing on the electrical characteristics of the patient's circuit will be discussed later

For the application of short wave diathermy by the condenser field, air spaced electrodes provide the most satisfactory method; but this method of applying high frequency energy for treatment is not as generally satisfactory, however, as the cable application

used with induction heating, or *inductothermy*, as induction-heating applied to tissue bas been apprnpriately termed

Tbe beating of tissue by inductinn is rapidly becoming more widely employed. Tbe desirable beating characteristics of the induction field, the adaptability nf the cable electrode to all anatomical parts, and the ease with wbich by means of such an electrode the desired distributinn nf pnwer input into the tissues can be achieved, make this methnd of application of higb frequency energy preferable to all nthers fnr medical use.

The high frequency current generated by a vacuum tube oscillator is conducted thrnugh a flexible, well-insulated cable, which is coiled around or about the part nf the body tn be treated. Tbis cable may also be wound into a *pancake* type of coil to be placed over the tissues in which heat is to be generated. The pancake type of coil may be permanently enclosed within an electrically non-conductive case tn form a drum or disc type applicator for the more cnnvenient treatment nf certain parts of the body.

Within and about the coil thrnugh which the higb frequency current from the nscillator flnws, there is set up an alternating magnetic flux, having the same frequency as the current in the coil. If a cnnductive material is placed within this bigb frequency magnetic field, an alternating electromntive force will be induced in it. As a result nf this induced voltage, eddy currents of the same frequency as the current in the coil will flow in tbe conductive material.

If living tissues are subjected to the high frequency magnetic field of the coil, there will be nn neuromuscular response to the eddy currents induced in the tissues, because the frequency of these currents is that of the excıtıng current in the coil, beıng of the order of 10 to 15 megacycles per second, a frequency far greater than those which elicit muscular contraction The energy of the eddy currents is converted into heat within the tissues ın which the currents flow, resulting in a temperature rise and those marked circulatory changes that normally follow the production of heat in living tissues. It will be shown later that the intensity of the eddy currents is greatest in the more conductive tissues, such as the vascular tissues and, consequently, the rate of heat

production will be greatest in such tissues, the very tissues in which heat is normally produced by energy metabolism

For the production of generalized fever, application of the induction field is made by means of a coil of a single turn, placed under the patient and extending from the shoulders to the feet of the patient The advantage of distributing the power input throughout the patient's body for the production of artificial fever, lies in the fact that the requisite input for elevating the patient's temperature can be made with a relatively low input per unit tissue volume To produce fever not only must there be an additional generation of heat within the patient's body beyond that generated by the patient himself, but *steps must be taken to minimize loss of heat from the patient* This application of high frequency power is discussed in detail in the section dealing with artificial fever

HEATING OF AN ELECTROLYTE BY HIGH FREQUENCY CURRENTS *Equivalent Electrical Circuit of an Electrolyte* An electrolytic solution may be considered a condenser having as a dielectric a conducting solution and as plates the two opposing surfaces of the electrolyte In a perfect condenser the current flow is a displacement current, for in a pure dielectric there are no free electrons to conduct current When an electric potential is impressed on such a dielectric, the bound electrons are displaced under the influence of the electric force until the force of attraction tending to hold the electron in its normal position with respect to the other charged particles making up the atoms and molecules of the dielectric equals the displacing force of the potential impressed on the dielectric The condenser will then be fully charged Further charge can be introduced only by increasing the potential Further displacement then takes place until equilibrium is again established between displacing force and the forces tending to oppose electron displacement If an alternating potential is impressed on the dielectric, the electrons will be displaced first in one direction and then in the other Overcoming the forces within the dielectric requires energy, and this energy loss manifests itself as heat, the so called *dielectric hysteresis loss*

In the case of an electrolytic solution, the current conducted by

the ions, into which the electrolyte on going into solution is dissociated, is very high in comparison with the displacement current for low frequencies; but as the frequency becomes higher, the displacement current becomes greater. At ultra high frequencies, the conductive current may be negligible in comparison with the

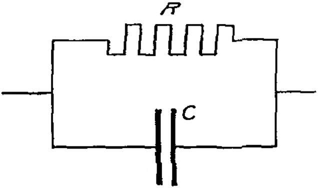

FIG 133 Simple equivalent circuit of an electrolyte

displacement current From an electrical viewpoint, an electrolytic solution may be represented in simplest form by a resistance, inclusive of the ohmic resistance of the dielectric and the resistance representing other power losses in the dielectric, connected in parallel with a capacitance. Fig 133. In Table 42 are given

TABLE 42

f (cps)	R (ohms)	X_C (ohms)	I_R (amps)	I_x (amps)
0	183	∞	0.547	0
100	183	22,500,000	0.547	4.45×10^{-4}
1,000	183	2,250,000	0.547	4.45×10^{-6}
10,000	183	225,000	0.547	4.45×10^{-6}
100,000	183	22,500	0.547	4.45×10^{-4}
1,000,000	183	2,250	0.547	4.45×10^{-6}
10,000,000	183	225	0.547	0.445
20,000,000	183	112.5	0.547	0.89
30,000,000	183	75	0.547	1.335
40,000,000	183	56.25	0.547	1.78
50,000,000	183	45	0.547	2.225

the resistance, the capacitive reactance, the energy component of current (conductive current), and the wattless component of current (displacement current), flowing through a 0 026 per cent electrolytic solution of NaCl for a constant effective value of impressed voltage for various frequencies ranging from zero (direct current) to 50,000,000 cps The voltage impressed on the electrolytic solution was taken as 100 volts effective, and the electrodes were assumed to be of the same size as the cross section of the electrolyte, namely 10 by 10 cms, spaced 10 cms apart *

* *Resistance of Electrolyte* The conductivity of an NaCl solution having a concentration of 026 per cent or about 026 grams NaCl per 100 grams of solution is $5\ 47 \times 10^{-4}$ mhos per cm.

The ohmic resistance of the electrolyte is given by the expression

$$R = 1/g\ l/A$$

in which R is resistance in ohms, g the specific conductivity in reciprocal ohm cms l the length of the electrolyte or distance between opposing surfaces in cms, and A the cross sectional area in sq cms

Substituting in this expression, we obtain for the ohmic resistance of the electrolyte

$$R = 1/(5\ 47 \times 10^{-4}) \times 10/(10 \times 10) = 183 \text{ ohms}$$

Since the dielectric is a conductive solution the dielectric hysteresis loss will be very small in comparison with the ohmic resistance loss and hence the total resistance will be considered composed only of the ohmic resistance Furthermore, the resistance will be assumed constant for all frequencies of current. The absence of the so-called skin effect in conductors having the relatively low conductivity or high resistivity of salt solutions of the order of 1 per cent concentration has already been discussed

Capacitance of Electrolyte The geometric capacitance of a parallel plate condenser is

$$C = KA/(4\pi d) \times 1/9 \times 10^{-11} \text{ farads}$$

in which K is the dielectric constant of the dielectric A the area in square cms of the plate which in this case is the same as the cross sectional area of the dielectric and d the distance in cms between opposing surfaces of the electrolyte which are considered the plates of the condenser The dielectric constant of 0 026 per cent saline solution we will assume to be 80

Substituting in the foregoing expression we obtain for the capacitance of the electrolyte

$$C = \frac{8\ 9 \times 10^{-11} \times 100}{4\pi \times 10} = 0\ 71 \times 10^{-10} \text{ farads.}$$

Obviously, as the frequency is increased, the proportion of the

total current that is productive of heat in the electrolyte decreases Hence, for the frequencies used in short wave diathermy, the reading of a series ammeter cannot be taken as being indicative of the power absorption of tissue, which electrically is comparable

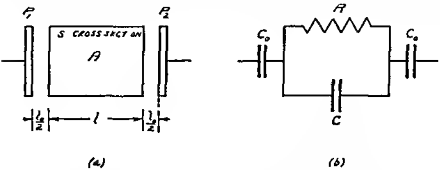

FIG 134 (a) Application of high frequency electric field to an electrolyte Electrodes P and P₁ are each $l/2$ cms from the electrolyte A and have the same area as the cross section of the electrolyte (b) Equivalent circuit of the application shown in (a)

to an electrolytic solution Nor can the ammeter reading be taken as a guide to the duplication of treatment unless the same frequency, the same sized electrodes the same load and the same voltage be used In a subsequent section the determination of power taken by an electrolyte or by any load will be discussed

Heating by Condenser Field In Figure 134 a is represented

Capacitive Reactance The capacitive reactance X_0 due to this capacitance equals $1/(\omega C)$ or $1/(2\pi fC)$ or $(225 \times 10^{10})/f$ ohms.

Energy and Wattless Components of Current The current flowing in the branch of the equivalent parallel circuit of the electrolyte which contains only resistance will be in phase with the impressed emf and hence will be an energy component Since the second branch contains no resistance only reactance the current in the first branch will be the total energy component of the total current taken by the electrolyte Likewise the current taken by the capacitive branch of the equivalent circuit is the total wattless component. If I_R is the energy component

$$I_R = E/R = 100/183 = 0\ 547 \text{ amperes}$$

and if I_X is the wattless component

$$I_X = 100/X_0$$

The wattless component will increase with increase in frequency whereas the energy component will remain constant for the conditions assumed in this problem.

an electrolyte to which high frequency power is applied by means of electrodes having the same area as the cross-section of the electrolyte. These electrodes, P_1 and P_2, are placed symmetrically at a distance $l_o/2$ cm. from the electrolyte. The cross-section of the electrolyte is S sq. cm, and its length is l cm In Fig. 134-b is represented in simplest form the equivalent circuit of the electro-

TABLE 43

CONSTANT CURRENT OF 1 AMPERE

Conductivity (ohm^{-1} cm^{-1})	Power in Watts			
	10 MC	20 MC	30 MC	50 MC
0	0	0	0	0
1×10^{-4}	48	12 48	5 6	2 02
2	84	24 12	11 0	4 02
3	104 4	35 2	16 08	5 88
4 45	112 4*	—	—	—
5	111 6	48	24 68	9 64
8 9	—	56 4*	—	—
10	83 2	56	36 0	16 8
13 35	—	—	37 0*	—
20	47 6	41 6	34 6	22 4
22 25	—	—	—	22 48*
30	32 6	30 68	27 88	21 52
50	19 84	19 4	18 68	16 72
100	9 96	9 88	9 80	9 54
500	2 00	2 00	2 00	2 00

* Indicates Maximum

lyte and coupling electrodes. The capacitance C_o is that between each electrode and the electrolyte. The electrolyte itself is represented by the resistance R in parallel with the capacitance C. Application such as this is termed short wave diathermy by air-spaced electrode technic.

The power absorbed by the electrolyte is a function of the frequency of the current and the conductivity and dielectric constant of the electrolyte. In Table 43 are given the computed power absorptions for various conductivities of the electrolyte and for various frequencies on the basis of constant current flow; and

in Table 44 similar computed power absorptions on the basis of constant voltage between electrodes The following dimensions (see Fig 134 a) were assumed for these computations $S = 100$ sq cm, $l = 10$ cm, and $l_o = 2$ cm *

* *Power Absorption by an Electrolyte in a High Frequency Electric Field* When setting up an equivalent electrical circuit to represent the impedance of an electrolyte to the flow of an alternating current, capacitance due to polarization at the boundary of the metal electrode and the solution must be taken into consideration This capacitance does not constitute a pure condenser but rather a leaky condenser Connected in series between the two leaky condensers one at each electrode, is another leaky condenser, whose parallel resistance represents the ohmic resistance of the electrolyte and whose capacitance is the capacitance between the electrodes, or rather between the inner surfaces of the polarization films with the solution as a dielectric

In this discussion let us assume that the electrodes are equal in size to the cross section of the electrolyte and that each is placed a distance $l_o/2$ cm. from the electrolyte, whose length is l and whose cross section is S sq cms, as shown in Fig 134-a.

Fig. 135 shows the equivalent circuit of the electrolyte and electrodes Z_1 the impedance of each of the polarized films consisting of a leakage re-

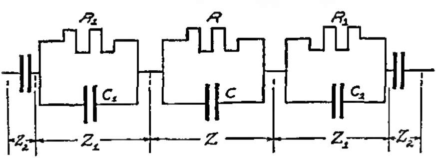

Fig 135 Equivalent circuit of application shown in Figure 134-a, inclusive of polarized films at the boundary of the electrodes and the solution.

sistance R_1 connected in parallel with a capacitance C_1, Z, the impedance of the electrolyte, consisting of a capacitance C connected in parallel with a resistance R, which is the ohmic resistance of the electrolyte between the polarized films, and Z_2 the impedance of each of the condensers formed by the plate electrode and the surface of the electrolyte with the intervening air as the dielectric, consisting solely of the capacitance C_2 since losses in an air condenser are negligible If a material other than air had been used between the plate electrodes and the electrolyte, appreciable power loss would have resulted Under such conditions the impedance of the condensers would not have consisted solely of a capacitive reactance.

TABLE 44

CONSTANT VOLTAGE OF 2000 VOLTS

Conductivity (ohm^{-1} $cm.^{-1}$)	Power in Watts			
	10 MC	20 MC	30 MC	50 MC
0	0	0	0	0
1×10^{-4}	13 2	13 7	13 8	13 8
2	23 48	26 6	27 2	27 5
3	29 6	37 8	39 8	40 9
4 72	32 8*	—	—	—
5	32 72	54	61 5	66 2
9 44	—	65 5*	—	—
10	25 28	65 4	92 3	117 2
14 16	—	—	98*	—
20	14 64	50 5	92 5	161
23 6	—	—	—	163 2*
30	10 04	37 4	75 7	159
50	6 12	24	51 5	126

* Indicates Maximum

The data of Table 43 for constant current are plotted in Fig 136, showing the relationship existing between the two independent variables, the conductivity and the frequency, and the de

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The total impedance of the circuit in Fig 135 can be shown to be

$$Z_t = \left(\frac{R}{1+\omega^2C^2R^2} + \frac{2R_1}{1+\omega^2C_1^2R_1^2}\right) - j\left(\frac{\omega CR^2}{1+\omega^2C_1^2R_1^2} + \frac{2\omega C_1R_1^2}{1+\omega^2C_1^2R_1^2} + \frac{2}{\omega C_1}\right)$$

R_1 and C_1 are very large whereas R and C are small Therefore, the foregoing expression for impedance may be simplified for all practical purposes to

$$Z_t = \frac{R}{1+\omega^2C^2R^2} - j\left(\frac{\omega CR^2}{1+\omega^2C^2R^2} + \frac{2}{\omega C_1}\right)$$

Power Loss as a Function of Conductivity for Constant Current The power loss in the electrolyte is equal to the effective current squared times the effective resistance of the electrolyte, or

$$P = I^2 \frac{R}{1+\omega^2C^2R^2}$$

pendent variable, the power absorption of the electrolyte The locus of the points whose co ordinates satisfy the equation for power absorption is a surface in space If a plane is passed through

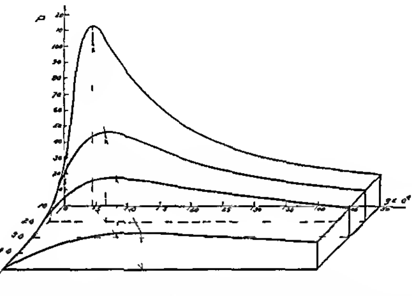

FIG. 136 Power absorption by an electrolyte in a high frequency electric field for constant current. Power absorption P is plotted against conductivity g and frequency *f* Data taken from Table 43

this surface parallel to the g P plane and intersecting the *f axis* at any given frequency, that plane will intersect the surface in a curve which represents the relationship existing between conductivity and power absorption of the electrolyte for the particular *frequency at which the plane intersects the frequency axis*

The ohmic resistance of the electrolyte is

$$R = 1/g \; l/S \text{ ohms}$$

where g is the conductivity in ohm^{-1} cms^{-1} l the length in cms and S the cross section of the electrolyte in sq cms

The capacitance of the parallel plate capacitor formed by the two opposing surfaces of the electrolyte as plates and the electrolyte as the dielectric is

$$C = KA/(4\pi d) \text{ farads}$$

when K is the dielectric constant of the electrolyte *In this discussion we will*

Other planes may be passed through the surface in space in a similar manner obtaining curves of conductivity versus power absorption for other frequencies. If a plane perpendicular to the plane of the *g-axis* and the *f-axis* is now passed through the maxima of the curves just obtained, that plane will intersect the plane of the conductivity-axis and the frequency-axis in a straight line that gives the relationship that must exist between the conductivity of the electrolyte and the frequency of the current in order that maximum power be absorbed by the electrolyte

In a similar manner the data of Table 44 for constant voltage is plotted in Fig. 137 As the frequency is increased, the power absorption increases. This is due to the fact that the impedance of the circuit decreases with increased frequency, permitting a greater flow of current through the electrolyte for a given voltage By passing planes through the surface obtained by plotting in space the corresponding values of conductivity, frequency, and power, curves similar to those obtained in this manner in the case of constant current may be determined.

It is evident from an inspection of the curves plotted from the data in Tables 43, 44, that, as the frequency is increased, maximum heating is obtained in electrolytes of higher and higher

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assume $K = 80$, and will assume it constant for all frequencies and conductivities

Substituting these values in the expression for power and simplifying, we obtain

$$P = 4I^2 \cdot \frac{l}{S} \frac{81 \times 10^{22} g}{f^2 K^2 + 324 \times 10^{22} g^2} \text{ watts}$$

Power Loss as a Function of Conductivity for Constant Voltage Impressed on the Electrodes With electrodes the same size as the cross section of the electrolyte, the expression for power is

$$P = V^2 \cdot \frac{lS}{l_0^2} \cdot \frac{f^2 g}{f^2\left(K + \frac{l}{l_0}\right)^2 + 324 \times 10^{22} \times g^2} \text{ watts}$$

where l_0 is twice the distance between electrode and electrolyte, K is 80, the dielectric constant of the electrolyte, which is assumed constant for all frequencies and conductivities, and V is the effective voltage impressed on the electrodes

concentration. If the current is kept constant, the relationship between conductivity and frequency for maximum heating remains constant regardless of air space between electrodes and electrolyte. However, if the voltage is kept constant and the current is permitted to vary, the relationship between the conductivity of

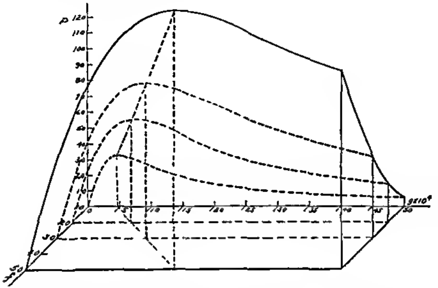

FIG 137. Power absorption by an electrolyte in a high frequency electric field for constant impressed voltage Power absorption P is plotted against conductivity g and frequency f Data taken from Table 44

the solution and the frequency for maximum power absorption will change with change in length of air space.*

* *Maximum Power Absorption* a. *For Constant Current* By differentiating the expression for power absorption with respect to conductivity and equating the derivative to zero, the following relation for maximum power absorption is obtained

$$g = f\,K/2\cdot 1/(9 \times 10^{11})$$

where g is the conductivity in $ohm^{-1}\ cms^{-1}$, f the frequency in cycles per second, and K the dielectric constant

In Table 45 is given the conductivity in $ohm^{-1}\ cms^{-1}$ of the electrolyte which absorbs maximum power at various frequencies

In Fig 138 conductivity of solution is plotted against frequency for maximum power absorption I, for constant current, II, III, IV, and V, for constant voltage for ratios of length of electrolyte to the length of air space of 1, 5, 10, and 20, respectively By decreasing the length of the air space, the conductivity of the electrolyte having maximum absorption of power for a given fre quency will be increased For a frequency of 40 mc, the con ductivity for maximum power absorption is 18×10^{-4} ohm^{-1} cm^{-1} when $l/l_o = 1$, and 22.2×10^{-4} ohm^{-1} cm^{-1} when $l/l_o = 20$ These conductivities, at the temperature of 25° C, correspond

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TABLE 45

CONDUCTIVITY FOR MAXIMUM POWER ABSORPTION
(Constant Current)

f in cps	g in ohm^{-1} cms^{-1}
10×10^6	000445
20	00089
30	001335
40	00178
50	002225
60	002670
70	003115
80	003560
90	004005
100	004450

b *For Constant Voltage* Treating mathematically in a similar manner the expression for power absorption for constant voltage we obtain for maximum absorption of power

$$g = \tfrac{1}{2} f\left(K + \frac{lK_o}{l_o}\right) \frac{1}{9 \times 10^{11}}$$

where K_o is the dielectric constant of the air in electrostatic units and l_o twice the distance between the electrode and the electrolyte assuming the electrodes to be symmetrically placed on either side of the electrolyte. The other terms represent the quantities as given in the preceding discussion

In Table 46 are given the computed conductivities for maximum power absorption for various frequencies and ratios of thickness of electrolyte to

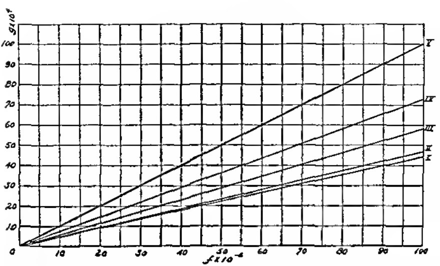

FIG 138 Conductivity of an electrolyte for maximum power absorption in a high frequency electric field plotted against frequency I for constant current, II, III, IV, and V for constant voltage and constant ratio l/l_e, of 5, with k_e, the dielectric constant of material interposed between electrodes and electrolyte, equal to 1, 5, 10, and 20 e s u, respectively

to the following concentrations of NaCl solution, 0 090 and 0 112 grams per 100 grams of solution, respectively Obviously from

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total air space, that is, for various ratios of l to l_e, with voltage kept constant between the electrodes

TABLE 46

CONDUCTIVITY FOR MAXIMUM POWER ABSORPTION
FOR VARIOUS FREQUENCIES AND RATIOS OF l TO l_e
(Constant Voltage)

f in cps	g in ohm^{-1} cms^{-1}			
	$l/l_e=1$	$l/l_e=5$	$l/l_e=10$	$l/l_e=20$
10×10^6	$4\ 5\times10^{-4}$	$4\ 72\times10^{-4}$	$5\ 0\times10^{-4}$	$5\ 55\times10^{-4}$
40	18 0	18 88	20	22 2
80	36 0	37 76	40	44 4
100	45 0	47 2	50	55 5

In Table 47 are given the computed conductivities for maximum power

this viewpoint there is no great advantage to be obtained by decreasing the length of the air space, especially in view of the fact that shortening the air space results in greater concentration of lines of force at the electrode with consequent greater heating in the superficial layers of the tissue

Heating by the Induction Field. Fig 139-a represents an electrolyte encircled by several turns of the flexible, insulated cable used for applying high frequency energy by induction The small condensers between the turns of the coil and between the coils and the electrolyte represent the capacitances present The capacitive reactance of these condensers is inversely proportional to the frequency of the current impressed on them If the frequency is excessively high, leakage of current will occur between turns, between turns via the superficial surface of the electrolyte, and from the turns to the electrolyte, which might be considered capacitively grounded Such leakage is due to the potential dif-

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absorption for various frequencies and various values of the dielectric constant of the dielectric between electrodes and electrolyte, with voltage kept constant between the electrodes and with a constant ratio of *l to l_e* of 5

TABLE 47

CONDUCTIVITY FOR MAXIMUM POWER ABSORPTION FOR VARIOUS FREQUENCIES AND VALUES OF K_e
(Constant Voltage and Constant Ratio l/l_e of 5)

f in cps	g in ohm^{-1} cms^{-1}			
	$K_e=1$	$K_e=5$	$K_e=10$	$K_e=20$
10×10^6	$4\ 72\times10^{-4}$	$5\ 84\times10^{-4}$	$7\ 22\times10^{-4}$	$10\ 0\times10^{-4}$
20	9 44	11 68	14 44	20
30	14 16	17 52	21 66	30
40	18 88	23 36	28 88	40
50	23 60	29 20	36 10	50
60	28 32	35 04	43 32	60
70	33 04	40 88	50 54	70
80	37 76	46 72	57 76	80
90	42 48	52 56	64 98	90
100	47 20	58 40	72 20	100

ference existing between these elements The resulting heating of the electrolyte will be partially induction heating and partially condenser field heating. It is desirable in this type of application to keep the frequency of the current at as low a value as is practicable and the spacing between turns and between the turns of

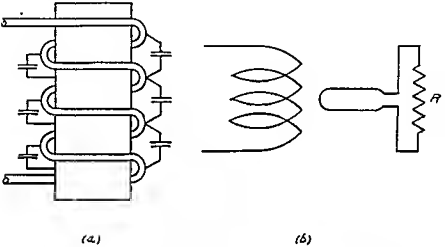


FIG. 139 (a) Application of a high frequency induction field to an electrolyte (b) Simple equivalent circuit of application shown in (a), assuming current leakage through capacitances shown in (a) to be negligible

the coil and the electrolyte sufficiently great in order that condenser field heating of the tissues exposed to the induction field will be negligibly small in comparison with the induction heating. We will assume that this is done, and therefore may consider the equivalent electrical circuit of an electrolyte, placed within a coil through which a high frequency current is flowing, as an air-cored transformer (a radio frequency transformer) with a secondary of one turn short-circuited through a resistance This resistance represents the resistance of the path of the eddy currents which the alternating magnetic field induces in the electrolyte.

As the magnetic field of the coil alternates, electromotive forces are induced within the electrolyte causing circular currents to flow therein The frequency of these induced currents will be the

frequency of the current flowing in the cable These circular currents will not, therefore, produce neuromuscular response if the frequency of the exciting current is greater than those frequencies which elicit such response

In Fig 139 h is given the simple equivalent circuit of the arrangement shown in Fig 139 a It consists of an air cored transformer with a primary of 4 turns and a secondary of one turn shorted through a resistance R

The electromotive force induced in any circular current path of the electrolyte is proportional to the rate at which lines of magnetic force cut this conductor and hence to the product of the frequency and the magnetic field intensity Expressed in sym hols

$$E = K_1 f \mathcal{H}$$

where K_1 is a proportionality factor, f, the frequency, and the intensity of the magnetic field

The magnitude of the resulting current flow is ohviously pro portional directly to the magnitude of the induced emf and in versely to the impedance of the path Since the path is considered of relatively small cross section in comparison with its length, the impedance will consist for all practical purposes solely of the ohmic resistance of the path The ohmic resistance is inversely proportional to the conductivity of the electrolyte Hence the current flow will be directly proportional to the product of the induced voltage and the conductivity Expressed in symbols

$$I = K_2 \; Eg = K_1 \; K_2 \; f \; \mathcal{H} \; g$$

where K_2 is a second proportionality factor

Power ahsorhed in this circular elementary conductor of the electrolyte is equal to the square of the current times the ohmic resistance The power is therefore

$$P = I^2 R = (K_1 K_2 f \; \mathcal{H} g)^2 R,$$

but $R = K_3/g$, where K_3 is a third proportionality factor Suh stituting and performing the indicated mathematical operations we ohtain

$$P = K_1^2 \; K_2^2 \; K_3 f^2 \; \mathcal{H}^2 g \text{ or}$$

$$P = K \; f^2 \; \mathcal{H}^2 \; g \text{ watts}$$

where $K = K_1^2 \; K_2^2 \; K_3$

From the foregoing expression one concludes that, if the frequency is kept constant and the intensity of the field is kept constant, the power absorption should be directly proportional to the conductivity of the electrolyte The rise in temperature of the electrolyte, assuming no loss of heat by radiation conduction,

TABLE 48

HEATING OF ELECTROLYTE BY INDUCTION FIELD
(Constant Current)

m Concentration in grams per 100 grams sol	ΔT Relative Rise		m/ΔT	
	Theoretical	Experimental	Theoretical	Experimental
0	0%	0%	—	—
0 1	11 6	—	0086	—
0 2	23 1	—	00865	—
0 27	—	32 3	—	0084
0 4	46 5	—	0086	—
0 47	—	56 5	—	00834
0 6	70 0	—	0086	—
0 67	—	78	—	0086
0 8	94 0	—	0085	—
0 85	100 0	—	0085	—
1 0	118 0	—	00849	—
1 07	—	126 5	—	00845
		Av	00856	00845

or convection will be inversely proportional to its thermal capacity the thermal capacity being the product of the mass of the electrolyte and its specific heat

In Table 48 are recorded the relative theoretical and experimental temperature rises obtained in an electrolyte placed within a coil of 4 turns using a frequency of 11 4 megacycles per second and a current of 10 amperes, which was kept constant for all concentrations of the electrolyte (NaCl) The time of application was 5 minutes The rise obtained for the concentration of 0 85 grams per 100 grams of solution (isotonic saline solution) was taken as 100 per cent in the case of both theoretical and experi

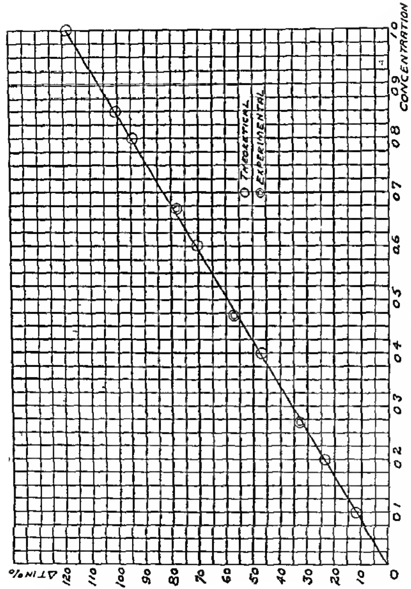


FIG 140 Relative experimental and theoretical temperature rises obtained in an electrolyte in an induction field plotted against concentration in grams of NaCl per 100 grams of solution Data taken from Table 48

mental values. The temperature rises obtained for other concentrations were expressed as percentages of this. Relative heating of the electrolyte is plotted against concentration in Fig. 140.

The linearity existing between temperature rise and concentration of electrolyte, assuming all other variables constant, lead to the obvious conclusion—that in the induction field heating is produced in an electrolyte in direct proportion to its concentration and hence to the conductivity of the electrolyte for the range of concentrations we are concerned with, namely from 0 to 1 per cent. Therefore, in the case of a body made of materials of various conductivities, heat will be produced at a greater rate in those materials of higher conductivity than in those of lower. In the case of living tissue subjected to the induction field, heat should therefore be developed primarily in the conductive and hence vascular tissues rather than in fat and other tissues of low conductivity.

Distribution of Magnetic Field Within a Coil Applicator. The intensity of the magnetic field within a coil, through which a current is flowing, is a maximum immediately within the coil. Curve A, Fig. 141, shows the variation in intensity of the magnetic field along a diameter of a coil of one turn, plotted in terms of the intensity obtaining at the midpoint on the diameter. Assume a cubic centimeter of a non-magnetic, electrically conductive material placed at the center of the coil (point P). Due to the alternating magnetic flux, eddy currents will be induced in the cubic centimeter of material and heat will be generated. The amount of heat generated per unit time will be proportional to the square of the average effective intensity of the magnetic field to which the specimen is subjected. For example, if the intensity of the magnetic field should be doubled at this point, the heat produced in the specimen would be quadrupled. As the cubic centimeter is moved along the diameter towards either side of the coil, it is subjected to stronger and stronger magnetic fields. The heat developed in it increases much more rapidly, however, than does the intensity of the magnetic field Curve B, Fig. 141, shows the variation in eddy current heating effect along the diameter of

a coil of one turn in terms of the heating effect at the center of the coil

Hence, if the cable of the induction type of short wave diathermy

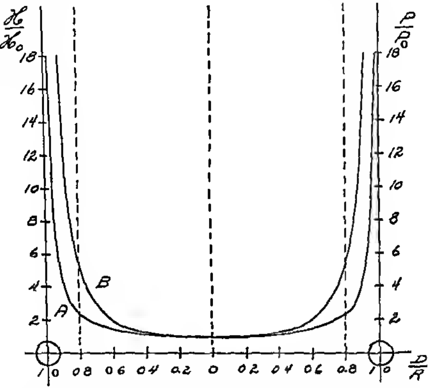


FIG 141 Curve A intensity of the magnetic field at any point on the diameter of a coil of one turn with radius R cms D cms from the center in terms of the intensity at the center ($\mathcal{H}/\mathcal{H}_0$) Curve B power absorbed by and consequently heat developed per unit time in a cubic cm of a non magnetic conductive material at any point on the diameter of the coil in terms of the power absorbed by the cubic cm. of material at the center of the coil (P/P_0)

apparatus is coiled snugly around the patient's body or part thereof heat will be produced at a faster rate in the tissues immediately within the coil than in the deeper tissues which are at a greater distance from the turns of the coil This will occur under such conditions of application even though the conductivity of

the deeper tissues may be greater than that of the skin and other superficial tissues of low conductivity. The lower electrical conductivity of these superficial tissues will be more than compensated for, as regards the production of heat, by the greatly increased magnetic intensity to which these tissues are subjected. Since the production of heat by eddy currents per unit volume of a non-magnetic conductive material is directly proportional to the square of the effective field strength and to only the first power of the electrical conductivity, a decrease in electrical conductivity to one quarter would be offset by doubling the intensity of the magnetic field. From an inspection of Curve A, Fig 141, this intensity of magnetic field, in comparison with the intensity at the center of the coil, is obtained approximately at points which are located about 0 8 of the radius from the center of the coil. All the points within the coil, having this intensity, lie in the plane of the coil and on the circumference of a circle with its center at the center of the coil, and with a radius equal to 0 8 of the radius of the coil.

From an inspection of Curve A, Fig. 141, one observes that the intensity of the magnetic field does not increase rapidly until a point greater than 0 8 of the radius from the center of the coil has been reached. In order that excessive heating of the skin and superficial tissues may be avoided and, to use a term from the nomenclature of x-ray therapy, to assure a high ratio of depth dose to skin dose, adequate spacing between coil and tissue must be provided. Absorbent towelling to a thickness of approximately 10 per cent of the diameter of the coil, or 12.5 per cent of the diameter of the member about which the cable is coiled, should be applied before applying the coil. If a thigh 6 inches in diameter is to be treated, towelling providing spacing of at least ¾ inch should be wound about the thigh before the cable electrode is applied. Although greater spacing may be employed, thereby assuring greater uniformity of the intensity to which the thigh is subjected, too great a spacing would appreciably reduce the coupling and hence absorption of energy. However, with technics now being rapidly adopted, employing low power inputs for relatively long periods of time for the purpose of inducing and main-

taining an active hyperemia, greater spacing may advantageously be used to assure more uniform field intensity and hence optimal ratio of depth heating to superficial heating

When the flat *pancake* type coil is used, adequate spacing between the coil and the patient's skin should also be provided in order that high rate of heat production with consequent excessive heating in the superficial tissues, due to the high field intensity close to the coil, be prevented

The purpose of the foregoing discussion is not to suggest actual measurement of the part to be treated and actual computation from such measurements of the spacing to be employed, but rather to provide reasons for introducing adequate spacing and to encourage the intelligent exercise of care in applying the induction field, based on a working knowledge of the field distribution, in order that full advantage of the physiologically sound heating characteristics of the induction method of applying high frequency currents for generating heat in living tissues may be realized

OPTIMAL FREQUENCIES FOR CONDENSER FIELD AND FOR INDUCTION FIELD APPLICATION *Condenser Field Application* It was shown in a foregoing part of this section that, when the condenser field is employed, maximum power absorption occurs in electrolytic solutions of higher and higher concentration as the frequency is increased A definite relationship exists between the frequency of the field, the dielectric constant of the electrolyte, and its specific conductivity for maximal absorption of power as has been shown

It was rashly concluded from such observations on physical phantoms that, knowing the dielectric constant and the specific conductivity of various organs and tissues in the body, frequencies could be selected to elevate the temperature of these organs and tissues without elevating the temperature of other organs and tissues However, the efficiency of the blood stream in dissipating heat and conveying it to other structures of the body tends to equalize temperatures and hence to prevent such specific heating Furthermore, there is no conclusive evidence to substantiate the claims for specific bactericidal effects of the various frequencies that have been employed in short wave diathermy ranging from

100,000,000 to 10,000,000 cycles per second, or, in terms of the wavelength of the radiation emitted by the oscillators, from 3 meters to 30 meters.

All of the effects that have been observed can be explained on the basis of heat production and the physiological effects which normally follow the production of heat in living tissue. Since, therefore, the production of heat seems instrumental in bringing about the results desired, a frequency of current should be chosen which, keeping in mind the fact that a certain frequency will heat more strongly an electrolyte of a given conductivity than another, will produce maximum heating in the vascular tissues. For it is in such tissues that heat is normally produced in the body through energy metabolism. To assure a high rate of heat production in such vascular tissues, relatively high frequencies in comparison with those employed for induction heating must be used Theoretically, a frequency of some 300,000,000 cycles per second, corresponding to a wavelength of the order of 1 meter, would have to be used to bring the peak of the curve showing heat production in an electrolyte for various concentrations to the concentration of isotonic saline, 0 85 grams per 100 grams of solution, having the conductivity of blood plasma. It is impractical to employ oscillators of such high frequency for the treatment of patients. Power required for local treatment, as actually measured by a high frequency wattmeter, ranges from 20 to 125 watts; for fever therapy, from 150 to 200 watts. An oscillator capable of generating a useful power output of the order of 200 watts at the frequency of 300 mc would be costly and of inconvenient size.

Muscle tissue is heterogeneous, consisting of conductive and non-conductive materials, having varying specific conductivities and dielectric constants. Furthermore, the specific conductivity, or, let us say, the specific resistance or resistivity of these materials, is not independent of frequency. According to data compiled by Bierman,[1] conductivity of muscle for the range of wavelengths

[1] Bierman, William The Medical Applications of the Short Wave Current. William Wood and Co (The Williams and Wilkins Company, Baltimore, Maryland) 1938

TABLE 49

ELECTRICAL CONSTANTS OF VARIOUS TISSUES AT DIFFERENT FREQUENCIES
(Taken from data compiled by Bierman, William
The Medical Applications of the Short Wave Current William Wood and Co, Baltimore Maryland 1938)

Tissue	Conductivity × 1000 (ohm^{-1} cms^{-1})				Dielectric Constant (e s u)		
	100×10^6	50×10^6	25×10^6	1×10^6	100×10^6	50×10^6	25×10^6
Muscle	8 1	8 1	8 1	6 3	73 8	89	108
Liver	6 1	5 5	5 2	2 5	78	90	137
Spleen	8 3	7 3		2 7	100	137	
Kidney	8 4	8 4		4 0	90	127	
Brain	5 4	5 1	4 3	1 4	83	112	160
Pancreas	5 4	5 4	5 4		67	96	158
Lung	2 9				38		
Fat	0 5	0 5	0 5	0 37	12	12	12
Bone Marrow	0 27	0 27	0 27		7 3	7 3	7 3
Whole Blood	11 0	11 0	11 0	7 3	74	89	140
Serum	16 0	16 0	16 0	16 0	76	76	76
Bile	16 7	16 7	16 7	16 7	78	78	78
Urine	34 0	34 0	34 0	34 0	76	76	76

3 to 12 meters (frequency 100,000,000 to 25,000,000 cps) is approximately 8×10^{-3} ohm^{-1} cm^{-1} The dielectric constant ranges from 73 8 to108 e s u for this range of wavelengths Table 49

All tissues are microscopically inhomogeneous They consist of cell contents, cell walls, and intercellular substance All have different conductivities and dielectric constants Therefore, the preceding arguments on the heating of homogeneous electrolytes by the high frequency electric field can not be applied readily to the heating of tissues except in a general way If the average conductivity and average dielectric constant of a microscopically inhomogeneous substance such as blood were determined, they would enable us to determine the variation in power absorption with change in frequency only for the material as a whole The different components of the tissue may heat differently From Fig 136, which shows the power absorption of a saline solution of various concentrations at different frequencies, it is seen that the power absorption is more uniform over the range of conduc-

tivity which includes those of biological importance for frequencies in excess of 20,000,000 cycles Hence, it would seem desirable to employ such frequencies when administering short wave diathermy by means of the electric field

If the application of the electric field is to be made by air-spaced electrodes, with an air space of one to two inches between tissue and electrode, relatively high frequencies should be employed in order that the requisite current may be passed through the series capacitive reactance, introduced by the air spaces, and the tissue to be treated in order to avoid the necessity of impressing an excessively high voltage on the electrodes Frequencies of the order of 40 to 50 megacycles, corresponding to radiation wave lengths of 7 5 to 6 meters, have been found satisfactory for this method of application

In view of the fact that power absorption varies for the different component elements of tissue when placed in a high frequency field, depending on their conductivity and dielectric constant, and in view of the fact that these different components undoubtedly differ in their ability to dissipate heat, it would seem possible that excessively high temperatures with consequent destruction might develop in certain cells or elements when tissue is subjected to the high frequency electric field Such excessive heating and resultant destruction might not be immediately detected The well known experiment of Esau indicates the possibility of producing isolated heating within the body of a heterogeneous substance In this experiment a salt solution was dispersed as an emulsion in paraffin oil and exposed to the high frequency electric field The suspended droplets of solution boil away although a thermometer suspended in the emulsion indicates a temperature below the boiling point of water

It would seem preferable to employ a method of application which would obviate the possibility of point heating In the case of the induction field, the power absorption by a substance exposed to the field has been shown, theoretically and experimentally, to be proportional to the product of the square of the induced emf and the conductivity Let us assume that a highly conductive electrolyte is encapsulated within a thermally and electrically

insulating membrane The power absorbed by the electrolyte, which will be high per unit volume because of its high conductivity, will be converted into heat and utilized in elevating the temperature of the electrolyte If the volume of the electrolyte is large, the total number of lines of magnetic force which cuts it per unit time will be relatively large, resulting in a higher induced emf and more intense eddy currents with consequent greater power absorption But if the volume is small, the number of lines of magnetic force cutting the electrolyte per unit time will be relatively small with consequent low induced emf, much less intense eddy currents, and considerably lower power absorption The resultant rise in the temperature of the two volumes may be comparable With the induction field, therefore, it appears improbable that point heating can be obtained unless the magnetic permeability of the particle is high The magnetic permeability of tissues is, however, comparable to that of air, and for all practical purposes may be considered unity

In reference to the possibility of heating one component of a microscopically inhomogeneous material more strongly than another in the high frequency electric field, it is pertinent to quote Bierman[a] regarding this possibility with respect to biologic materials

"For biologic materials, however, the cell dimensions are so small, and the thermal conductivity so great, that it is questionable whether such differential effects can show themselves as a substantial temperature difference Calculations on this question have been made and lead to a result which would seem to make this possibility a very doubtful one It has been calculated for the case of particles of diameter 5 μ, suspended in a watery medium, that a current density below those which would cause coagulation, a temperature difference of 1/100,000 degree is all that could be produced under optimum conditions (Krasny Ergen, W Hochfrequenz u Elektroak, 48 126 1936)"

Careful experimental work is indicated to determine definitely

[a] Bierman William The Medical Applications of the Short Wave Current William Wood and Co (The Williams and Wilkins Company Baltimore Maryland) 1938

whether undesirable heating of component elements of tissue occurs when exposed to the high frequency electric field.

Induction Field Application. As has already been pointed out, for a given number of turns and a given configuration of the cable of a short wave diathermy generator of the induction type, the power introduced into a given load will be proportional to a function of the frequency times the square of the intensity of the current flowing in the cable, the magnetic flux density being proportional to the current and the number of turns in the coil. In order to avoid the use of excessively high currents in the cable it is necessary to employ relatively high frequencies. Frequencies of the order of 10 to 15 megacycles have been found quite satisfactory. Such frequencies are far above those which elicit neuromuscular response, and hence the only effect of the currents induced in the tissues of a patient is the production of heat. Furthermore, for adequate heating of tissues such frequencies make unnecessary currents in the cable greater in magnitude than about 10 amperes. These frequencies correspond to wavelengths of the order of 20 to 30 meters.

If higher frequencies are employed, the cable tends to act like a distributed cuff electrode with current flowing from turn to turn through the patient's tissues, resulting in a relatively high surface heating. In fact, the use of very high frequencies and many turns of the cable may result in the type of heating obtained in the electric field of air-spaced electrodes Fig 142 gives the construction and dimensions of a phantom that was used in an experiment to determine whether higher frequencies could be as effectively employed for induction heating as those of the order of 10 to 15 mgacycles. The frequency of current in this test was 44.4 megacycles, corresponding to a wavelength of 6 75 meters Five turns were wound around the phantom. The concentration of the electrolyte was varied from 0 to 1 4 grams per 100 grams of solution. Current and time of application were kept constant for all concentrations The power absorption was determined and plotted as a percentage against concentration of electrolyte, taking the absorption of power for the concentration of 0 85 grams of NaCl per 100 grams of solution as 100 per cent Curve A of

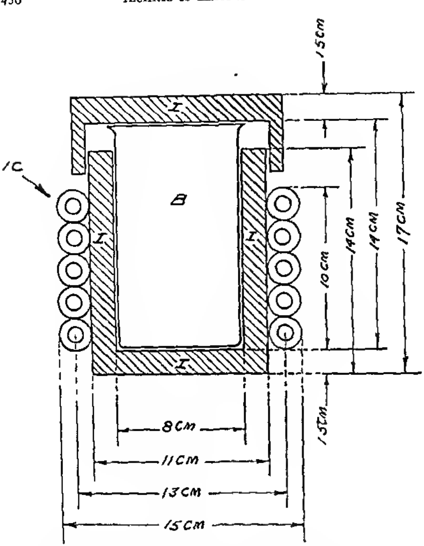


FIG 142 Phantom used to determine the heating characteristic of an induction field having a frequency of 44 4 megacycles (wavelength of 6 75 meters) B is a 500 cc beaker I insulation, and IC induction cable

Fig 143 is the curve plotted from the experimental data An inspection of this curve leads one to the conclusion that it is made up of two curves, one due to induction heating and the other due in all likelihood to the electric field between the turns of the

cable. The curve of induction heating for constant frequency and field intensity is a straight line and can be constructed approximately by drawing a straight line through the origin and the experimental points obtained for the higher concentrations This gives Curve B. If Curve B is subtracted from Curve A, Curve C is obtained. This curve represents heating due to the electric field between turns and has the form that is typical of the curve showing the heating characteristic of the electric field. According to the information given in a preceding part of this section, an electric field having a frequency of 44 4 megacycles should produce maximum heating in a NaCl solution having a concentration of about 0.117 grams NaCl per 100 grams of solution. Curve C of Fig. 143 has its maximum at approximately this concentration This experiment provides evidence in support of the statement that with excessively high frequencies the heating is not pure induction heating but a mixture of induction heating and electric field heating

Contrast the heating curve A of Fig 143 with the graph of heating versus conductivity shown in Fig 140 for a frequency of 11.4 megacycles The latter graph is perfectly linear, showing that heating of the electrolyte is primarily due to induction. From the discussion of the change in the inductance of a coil with increase of frequency, it will be concluded that the optimal frequency for induction heating should lie between 10 and 15 megacycles Experience has verified this theoretical deduction.

Measurement of Power Output and Power Absorption. In spite of the voluminous literature on the subject of short wave diathermy, it appears that the basic principles governing the absorption of power by a patient subjected to treatment are not thoroughly or generally understood. Therefore, an endeavor is made in the following to discuss these principles from a physical point of view in order that correct conclusions may be drawn with respect to the power that can be absorbed by a patient undergoing treatment.

It is obvious that to judge the heating power of a short wave diathermy generator, a knowledge of the maximum high frequency power which can actually be introduced into a patient by that

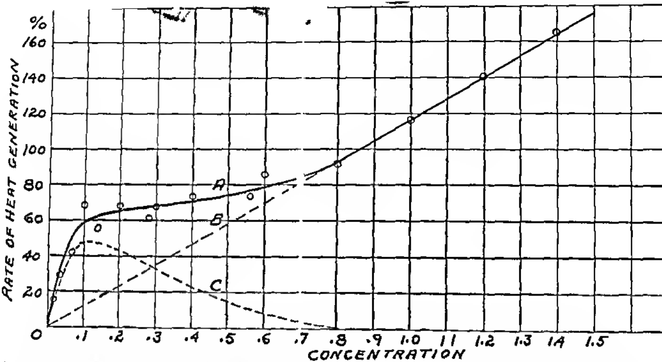


FIG 143 Heating characteristic of induction field at frequency of 44 4 megacycles (6 75 meters), using 5 turns of the cable around the phantom containing the electrolyte as indicated in Figure 142 The rate of heat generation for the concentration of 0 85 grams NaCl per 100 grams of solution (isotonic saline) was taken as 100 per cent *Curve A* is the total heating effect *Curve B*, that due to induction And *Curve C* that due to the electric field obtaining between the turns of the cable *Curve C* is obtained by subtracting *Curve B* from *Curve A* *Curve C* has a maximum at the concentration of approximately 0 11 grams NaCl per 100 grams solution From *Curve I*, Fig 138 the conductivity of an electrolyte for maximum power absorption in a high frequency electric field having a frequency of 44 4 [illegible]
used in this experiment [illegible]

generator is indispensable. The magnitude of this power determines the maximum power available from that generator for treatment purposes.

Heating power or *patient's power* we shall define as that fraction of the total power output which is absorbed by the patient under treatment. In contrast to this fraction of the total power, we shall define as *generator output* the maximum power which can be drawn from the generator under special optimal conditions. Under such conditions, the load which absorbs the maximum possible output, is said to be "matched" to the generator. The ratio of the heating or patient's power to the maximum available output depends on the construction of the generator and on the technic of application. This ratio denotes the effectiveness of the machine as a means of introducing energy into a patient and may be defined as its thermal effectiveness.

Inadequacy of Lamp Load Tests Various attempts have been made to measure the output power of short wave diathermy machines. Phantom loads consisting of lamps were used in the majority of these tests. Since the power rating of the lamps was known, the brilliancy of the lamps gave a fair estimate of the output of the machines Usually, the operating voltage of the lamps was chosen so that the phantom was "matched" to the generator to assure a maximum absorption of power. If we remember the fact that the high frequency resistance of the body—for instance, of the thorax between the electrodes of a short wave diathermy machine—is on the average small in comparison with the resistance of the lamps (50 to 100 ohms) in the tests mentioned, we can readily understand the significance of the following comparisons

Suppose we have two lamps each rated at 100 watts. The first one is designed for a voltage of 100 volts, whereas the second is for only 25 volts Since the wattage consumed by a lamp is the product of the current passing through the lamp and the operating voltage, a current of 1 ampere is required for the 100 volt lamp and 4 amperes for the 25 volt lamp to operate them at their rated power. This corresponds to a resistance of 100 ohms in the first, and a resistance of 6 25 ohms in the second lamp.

Suppose that we have a generator with a terminal voltage of 200 volts connected to the light socket through a long line having a resistance of 100 ohms Now if the 100 volt lamp is connected to the socket, a current of 1 ampere will flow through the lamp The lamp will light with full brightness, corresponding to the rating of 100 watts If the 25 volt lamp is substituted for the 100 volt lamp, the total resistance between the terminals of the generator will be 106 25 ohms The flow of current will now be 1 88 amperes instead of the 4 amperes required for full brightness The voltage across the lamp will be 11 75 volts instead of 25, and the power absorbed will be only 22 watts, although the lamp is rated at 100 watts In spite of the fact that in the second case we have only 22 watts of useful output, we must have a total output drawn from the generator of 376 watts against the total output of only 200 watts in the case of the 100 volt lamp, which yields a useful output power of 100 watts In the case of the first lamp, the load was matched to the generator, whereas in the case of the second lamp the load was not matched

Similar matching of load and generator is required to obtain maximum output from a short wave diathermy generator The lamp load having a higher resistance is better matched to the generator than living tissue with its comparatively low resistance Hence a higher output is always obtained with a lamp load than is obtained in clinical application

These theoretical considerations are fully confirmed by practical experience The figures in Table 50 definitely show that the output of a short wave diathermy machine measured by a lamp load does not indicate the effectiveness of such generator in heating tissues The table which is taken from a publication of Carter,[a] gives the temperature rise in the deep tissue of the human thigh after an application of 20 minutes In these tests instituted under authorization of the Council on Physical Therapy of the American Medical Association, the input into the patient was always adjusted to the limit given by the tolerance of the patient It should be noted that a high percentage of the generators

[a] Carter H A Power Measurements of Diathermy Apparatus Arch Phys Therapy 19 699 1938

having a high lamp load output produce a rather limited increase of the deep tissue temperature in comparison with generators having a smaller lamp load output.

It is only necessary to compare tests 8, 9, 10, 11 of the tests of induction cable machines, and tests 1 and 4 of the tests on generators using air-spaced electrodes, to prove the fallacy of lamp

TABLE 50

RISE IN DEEP TISSUE TEMPERATURE AS COMPARED WITH THE OUTPUT MEASURED ON LAMP LOAD PHANTOMS UNDER OPTIMAL CONDITIONS FOR VARIOUS MACHINES

	No	Output Watts	Temperature Rise in F°
A Induction Coil Technic	1	152	8 8
	6	152	6 6
	8	450	5 9
	9	520	5 8
	10	255	6 8
	11	345	5 7
	13	40	3 8
	14	410	3 0
B Cuff Technic	1	270	9.0
	5	450	7 2
	9	250	5 4
	12	420	4 0
C Air Spaced Technic	1	530	7 0
	4	500	2 5

load tests. In tests 8, 9, 10, and 11, practically the same increase in deep tissue temperature is obtained, between 5.7 and 5 9 degrees Fahrenheit, the deviation being only 2 per cent from the average. But the outputs of the machines as measured with the lamp method varied between 255 and 520 watts Even more significant are the results of tests 1 and 4 on generators using air-spaced electrodes. Two machines with outputs of 500 and 530 watts respectively produced a final temperature increase of 2.5 and 7 degrees respectively, a 270 per cent difference in temperature rise for two machines with practically the same lamp load outputs! Further confirmation of the unreliability of the lamp load test as an indication of the useful output of a generator may be found in tests 1, 5, 9, and 12 on generators using cuff electrodes.

The very fact that machines with apparently small outputs are able to produce a higher temperature increase in the deep tissue than machines with larger outputs indicates not only that the lamp load tests are without any meaning, but also that it is possible to build machines with small total power output but high thermal effectiveness.

Measurement of Power Absorbed by Patient. The power absorbed by a patient for any given generator varies widely with the technic of application and the part of the body which is being treated[4] The technics of application employed in determining the deep heating capacity of the various generators reported on by Carter were devised with the view of obtaining maximum input into the thigh of the subject and consequent high temperature rise. Although under such conditions a generator may produce adequate deep heating, it cannot be concluded that such generator will be able to produce comparable heating effects under different conditions of application. The only dependable means of estimating the actual heating power of a short wave diathermy generator under all conditions of application is a direct reading instrument which measures the actual power absorption in the body. Such an instrument was described by Mittelmann[5,6] To determine the approximate maximum heating value of a generator, a phantom which meets the electrical conditions under which the generator shall operate may be employed Since the power required for the heating of any part of the body to the same degree increases with the volume, it seems sound to choose that part of the body with the biggest volume as the theoretical load and to establish a phantom which is electrically equivalent to it. Such a phantom consists of a salt solution with a conductivity equivalent to that of the average conductivity of power absorbing human tissues. Since the average dielectric constant of human tissues, is approximately the same as that of water, namely 80, to

[4] Coulter, J S, and Osborne, S L: Short Wave Diathermy in Heating of Human Tissues Arch Phys Therapy 17 679.1936

[5] Mittelmann, E · Dosimetry in Short Wave Therapy Arch. Phys Therapy 18 613:1937.

[6] Mittelmann, E, and Kobak, D · Dosage Measurement in Short Wave Diathermy Arch. Phys Therapy 19 725.1938

match the phantom with the body considered under treatment it is necessary only to adjust the concentration of the salt solution. The equivalent conductivity of human tissues at high frequencies is the conductivity of a NaCl solution of 0.2 per cent concentration.[7,8,9] One of the main objections to the use of lamp load tests, even if lamps with very low resistances are used, is that lamps do not have the capacitive component of the body, and hence their impedance cannot be made to match that of the body.

To determine the relation between the maximum available power output and the heating power, or power absorbed by the patient, a number of machines were investigated. The heating power was determined by measuring the rise in temperature of an electrolytic phantom after a definite time of application. A volume of 3500 grams of salt solution was used in the tests. The time of application of power was the same in all tests, namely, 3.5 minutes.

For purposes of comparison the effectiveness as defined in the foregoing paragraphs was calculated in each instance by dividing the real therapeutic power by the maximum power output as measured by the lamp load test. On the average, the effectiveness was ⅓ to ½. However, it is by no means impossible to develop a generator having a thermal effectiveness which approaches the value of unity. (See test number 4 in Table 51.)

The measurements of patient power were carried out under optimal conditions, making such modification as to spacing, turns and size of electrodes as to obtain the maximum output. The values so obtained indicate the maximum heating power which can be obtained under optimal technics of application. They must not be interpreted to mean that such power absorptions can be obtained in every treatment application. The actual power absorption in clinical practice is usually but a fraction of these maximal

[7] Thomson, D. L. Internal Conductivity of Non irritable Muscle, J Physiol 65 214 1928

[8] Bozler, E., and Cole, K. S. Change of Alternating Current Impedance of Muscle Produced by Contraction. J Cell. & Comp Physiol, 6 229 1935

[9] Rajewski, B. H., Osken, H., and Schaefer, H. Hochfrequenzleitfähigkeit Biologischer Gewebe im Wellenlangenbereich von 3 bis 1400 Meter. Naturwissenschaften, 25 24 1937.

values and depends on the geometrical and electrical dimensions of the part treated as well as on the patient's tolerance In Figure 144 the useful or absorbed power from a short wave diathermy generator, utilizing the electromagnetic induction principle for heating,[10, 11] is plotted against the volume of an electrolytic phantom of 0 2 per cent concentration The power absorption was

TABLE 51

PATIENT POWER MEASURED BY CALORIMETRIC METHODS ON ELECTROLYTIC PHANTOMS AS COMPARED WITH THE MAXIMUM AVAILABLE OUTPUT MEASURED ON LAMP LOADS UNDER OPTIMAL CONDITIONS FOR VARIOUS MACHINES

No	Maximum Power Output Lamp Load	Technique	Patient Power Electrolyte Phantom	Thermal Effectiveness Per Cent
1	340 watts	pancake coil	109 watts	32 0
2	430 watts	cable, 3 turns	236 watts	53 0
3	196 watts	flat coil	111 watts	56 5
4	202 watts	cable, 3 turns	197 watts	97 0
5	320 watts	flat coil	42 watts	13 2
6	325 watts	cable, 3 turns	183 watts	56 0
7	325 watts	pads	105 watts	32 5
8	320 watts	pads	58 watts	17 8
9	475 watts	air space	228 watts	48 0
10	420 watts	cuff	82 watts	19 5
11	530 watts	air space	148 watts	36 5
12	270 watts	cuff	137 watts	50 5
13	470 watts	pads	242 watts	51 5
14	480 watts	pads	260 watts	54 0

measured both by calorimetric and by direct reading methods The power absorption increases with increasing volume until the limit of the available heating power is reached, and from then on the power absorption remains practically constant Power absorption obtained with different technics of application are shown by the curves

[10] *Merriman J R* and *Holmquest H J* and *Osborne S L* A New Method of Producing Heat in Tissues The Inductotherm Am Jour Med Sciences 187 677 1934

[11] Holmquest H J and Marshall J G Inductothermy Its Physical Basis and Technique of Application Brit Jour Phys Med 4 70 1936

The misleading use of the term "output power," meaning by this magnitude the total available output of a generator, has been and still is responsible for false conclusions as to the heating effectiveness of short wave diathermy generators Various measurements indicate that the wattage used in clinical practice is relatively small in comparison with the output power [22 23] The

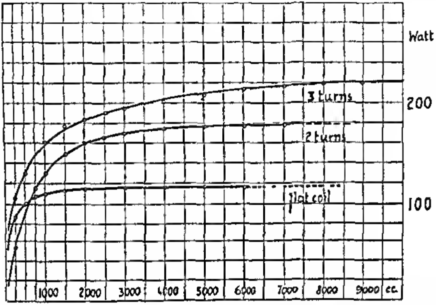


FIG 144 Curves showing the useful or absorbed power from a short wave *diathermy machine as compared with the volume of an electrolytic phantom* of 0 2 per cent concentration Application was made by means of the induction field

maximum power absorption which can be tolerated by a patient during a continuous local treatment is about 100 to 120 watts applied to large parts of the body Effective fever therapy can be administered with generators having no more than about 200 watts total output power but having a high thermal effectiveness The thermal effectiveness, or ratio of patient power to total

[22] Kowarschik J Dosage Measurement in Short Wave Diathermy Arch Phys Therapy 20 208 1939

[23] Mittelmann, E and Kobak D Dosage Measurement in Short Wave Diathermy Arch Phys Therapy 19 725 1938

available power, depends on the construction of the generator and the technic of application In other words, the construction of a generator and the technic of application will determine whether a smaller or larger total power is necessary to obtain the same amount of power absorption in a patient

Measurement of the Power Absorbed by the Body Under Treatment To determine the beating power of a generator under actual working conditions, it is necessary to employ methods which measure the actual power absorbed by the body, regardless of the construction of the machine and the technic of application

TABLE 52

TIME OF EXPOSURE AND POWER ABSORPTION FOR PATIENT'S TOLERANCE WITH GENERATORS WITH DIFFERENT OUTPUTS

No	Output Watt (Lamp Load)	Absorbed Power Watt	Time of Exposure Minutes
1	430	158	2
2	202	154	2
3	375	162	2

An instrument which measures power absorbed immediately answers the question whether the generator under consideration meets the heating requirements or not, regardless of which output powers are claimed as the maximal output

Provided the technic of application is not changed, the primary effect is governed solely by how much power is absorbed by the body For similar effects this power absorption must be the same whether it is achieved with a short wave diathermy generator of 1000 or with one of only 200 watt output To demonstrate the fact that for a given effect the power absorbed is the same for machines of different maximum available outputs, the following test was performed Three turns of the induction cable were applied to the thigh of a subject, and the power absorption measured by means of a high frequency wattmeter [14] The power input into the thigh was adjusted so that the patient's toler-

[14] Mittelmann E and Kobak D Dosage Measurement in Short Wave Diathermy Arch. Phys Therapy 19 725 1938

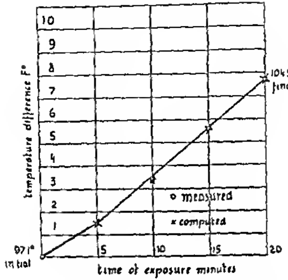
ance was reached in about 2 minutes. This test was repeated with different machines. The results tabulated in Table 52 show that for the same effect, namely, reaching tolerance of a patient in 2 minutes, there is no difference between the input powers of the different machines regardless of the claimed output. Tests with other machines employing air-spaced and pad electrodes gave similar results.[15]

In this test the wattmeter was calibrated for each machine The theory of the instrument and the procedure of the calibration are given in a later section of this discussion. The instrument has beneath the indicating meter a resistance with a calibrated dial. The figures on the dial are the same as those on the scale of the indicating instrument. Before applying the cable to the patient, the generator is switched on with the output control at lowest setting, and the output slowly increased until the pointer of the meter reaches full scale deflection. The patient is then introduced without changing the output control The deflection of the meter will decrease. The pointer of the dial is now set to correspond with the reading of the instrument. The instrument is now converted into a direct reading wattmeter, measuring the power absorbed by the patient. The output control can now be adjusted at will and the meter will always read the actual power absorption. The results of the measurements (Table 52) are in agreement with previous measurements. In the previous measurements the power corresponding to the patient's tolerance was practically the same for the various machines tested, namely, about 100 watts, whereas the maximum power output of the generators as measured by a lamp load varied between 210 and 700 watts.

Correlation of Power Absorbed with Temperature Rise in Deep Tissue. Three turns of an inductance cable were wound around the thigh of a subject and high frequency power was applied for twenty minutes Every five minutes the temperature in the deep muscle was measured by means of a thermocouple, employing the method of measurement described by Mortimer and Osborne[16]

[15] Mittelmann, E., and Kobak, D: Dosage Measurement in Short Wave Diathermy Arch Phys Therapy 19 725 1938

[16] Mortimer, B, and Osborne, S L: Tissue Heating by Short Wave Diathermy. J.A.M.A. 104.1413 1935



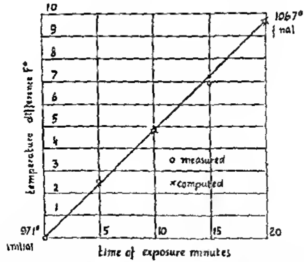


FIG 145 Computed and measured temperature rise in the deep tissues of the thighs of living subjects Computation of temperature rise was based on wattage absorbed as indicated by a high frequency wattmeter

(a) Patient J T age 23 weight 162 pounds Approximate volume of thigh surrounded by cable 3800 cc Power absorption 74 watts during the first 5 minutes 85 watts during the period 5 20 minutes

(b) Patient R McG age 37 weight 149 5 pounds Approximate volume of thigh surrounded by cable 3280 cc. Power absorption 88 watts

From the indicated wattage input and the approximate volume of the thigh within the coiled cable, the temperature rise in the tissue for each 5 minute period was computed Tests on various subjects were conducted Figures 145 a and 145 b are representative of the results obtained Not only is the remarkably close agreement between measured and computed rise in temperature worthy of note as evidence of the reliability of the wattmeter employed as an indicator of the actual heating power of a short wave diathermy generator, but also of significance is the fact that adequate heating is obtained with relatively low wattages, final temperatures of the order of 106° F with power inputs of the order of 80 watts being obtained

Theory of the Mittelmann Wattmeter The total power delivered by a short wave diathermy generator is divided into two components, namely, the patient's power and the radiation losses Both are subject to wide variation according to the technic of application, electrodes, air space number of turns in the case of the induction cable, and the current flow and its frequency of oscillation A determination of the amount of the absorbed energy is possible only if components of the total power output are separated[17] Figure 146 a shows schematically the object surrounded by the treatment cable of an induction type short wave diathermy machine * Electrically this corresponds to the circuit in 146 b, where the resistance R_p represents the equivalent loss resistance of the patient, coupled by a single turn to the primary of a high frequency transformer The resistance R_o represents the radiation losses and the losses caused by other components not taking part in the heating of the object These losses are independent of the object Every resistance in the secondary of a transformer can be converted into an equivalent resistance in the primary, which will absorb the same power as the resistance in the secondary which it replaces Let us therefore replace R_p with its equivalent primary resistance R'_p Fig 146 c

[17] Mittelmann E Dosimetry in Short Wave Therapy Arch Phys Therapy 18 613 1937

* This also represents schematically a clinical application such as the application to the thigh of a patient.

Assuming a resonant condition in the load circuit, the voltage across the primary coil will be proportional to the magnitude of the total equivalent primary resistance which is considered to be in parallel with the terminals This resistance represents the total

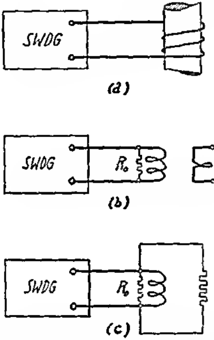


FIG 146 (a) Schematic representation of load coupled to inductance cable of a short wave diathermy generator SWDG (b) Equivalent electrical circuit of 146-a. R_o represents radiation and other losses, R_p, the equivalent loss resistance of the patient, which is considered coupled by a single turn to the primary of a high frequency transformer (c) Electrical equivalent of circuit of 146 b R'_p represents resistance in primary connected in parallel with R_o, which is equivalent to R_p

losses Let us consider first the no load condition We can then write

1. $$E_o = kR_o,$$

where k is a portionality factor, the value of which is determined by the coupling of the load circuit with other circuits, and which is assumed to be kept constant.

After the introduction of the object the primary equivalent resistance is made up of R_o and R'_p in parallel. Then we have

1a. $$E_p = k\frac{R'_pR_0}{R'_p + R_0}$$

where E_p denotes the value of the reduced voltage after the introduction of the object. Substituting E_o from equation 1 for kR_o in equation 1a, we obtain

2. $$R'_p = R_0\frac{E_p}{E_0 - E_p};$$

or if we express R'_p and R_o in terms of their corresponding conductances, i e., $R'_p = 1/G'_p$ and $R_o = 1/G_o$, equation *2* becomes

2a. $$G'_p = G_o\frac{E_o - E_p}{E_p}.$$

The value of the patient's equivalent conductance thus being determined, the power absorption for any voltage E is given by the product $E^2\ G'_p$, in which E is the effective or root mean square value of the voltage. If G'_p is known, then the power absorption can be determined by the measurement of the square of the effective voltage. If both E_o and G_o are constant, the value of the *equivalent primary loss conductance* G'_p, *introduced* by the patient into the circuit, will be determined by the magnitude of the voltage E_p across the terminals of the coil after the introduction of the patient. Thus we can express the ratio of G'_p to G_o in terms of E_p. If we measure the voltage across the terminals by a thermocouple suitably coupled to the terminals, the direct current voltage developed across the d.c. terminals of the couple will be proportional to the quantity E^2. When using a galvanometer to indicate the magnitude of the d c. voltage of the thermocouple, the deflection of the meter will be $D = AeS.$, denoting by e the d.c. voltage of the couple, by S the sensitivity of the meter, and by A the proportionality factor. If we vary S in such a way that it shall be always proportional to the value of the equivalent primary loss conductance introduced by the

patient, the meter will read the power absorbed by the body The sensitivity of the meter can be easily varied by means of a variable resistance in parallel with the galvanometer

To calibrate the instrument it is only necessary to introduce into the coil an electrolytic phantom matching the electrical properties of the body The procedure is as follows Set sensitivity control dial at maximum setting, thereby introducing entire resistance of sensitivity control in parallel with the galvanometer Then observe the voltage E_o at a reduced output setting of the generator and without the phantom in the coil By means of the output control of the generator, E_o is varied until the pointer of the meter reaches full scale deflection, which corresponds to E'_o The phantom, the thermal capacity of which is known, is introduced The temperature of the solution and the reduced deflection of the meter which now corresponds to E'_p, are noted The phantom is subjected to the field for *n* minutes using any desired setting of the power control At the end of the run the temperature is measured carefully and the rise in temperature computed If the temperatures are measured in F°, the power absorbed in watts is equal to

$$\frac{38\ 8 \times \text{temperature rise} \times \text{volume in liters}}{\text{time in minutes}}$$

If the time of run in minutes is always chosen numerically equal to the volume of the phantom in liters, the graph in Fig 147 can be used for the quick determination of power absorption

After the power absorption is known, the output control is readjusted if necessary, until the meter indicates the same deflection as during the test The parallel resistance of the meter is now varied until the meter deflection indicates the same value of power absorption as obtained by the calorimetric measurement Several points of the scale are calibrated in the same way Variation in power absorption can be obtained by varying the geometric position of the phantom in the magnetic field as well as by varying the power control of the generator The load circuit must always be adjusted for resonance, however

If we plot the values of the parallel resistances corresponding

to the deflections indicating the value of E^2_0 for various loads, we obtain the calibration curve of the meter, Fig. 148. The accuracy of the calibration is then checked by measurements carried out with the phantom The deviation between meter reading and calorimetric determination of power absorption must not exceed 5 per cent. For convenience, the plotting of the calibration curve

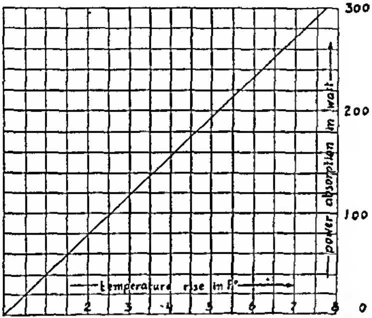
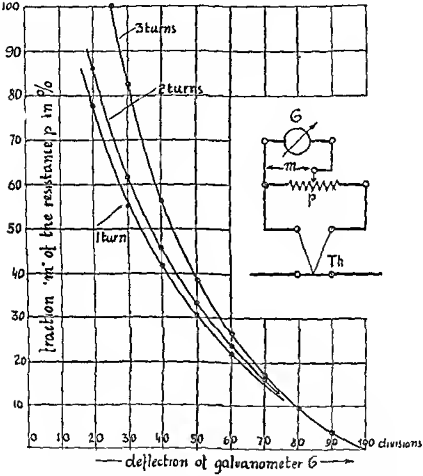


FIG 147 Graph for determining power absorbed by phantom during calibration of wattmeter from temperature rise of electrolyte, assuming time of application to be equal in minutes to volume of phantom in liters

is not in terms of resistance values against meter deflections, but rather in terms of resistance dial settings against meter deflections

Since the value of the equivalent conductance in the primary varies with the transformer ratio, calibrations were made for 1, 2, and 3 turns of the inductance cable Calibration curves are given in Figure 148. Dial settings are plotted against corresponding meter deflections after the introduction of the phantom into the field.

DETERMINATION OF USEFUL OUTPUT AND HEATING CHARACTERISTICS OF SHORT WAVE DIATHERMY GENERATORS The measurement of the total power that a short wave diathermy machine is capable of introducing into a given part of the human



IG. 148 Calibration curves of meter for 1, 2, and 3 turns of induction cable Electric circuit of high frequency wattmeter is also shown

y is not sufficient information on which to base an estimate the effectiveness of that machine as a means of heating tissues.

Not only the maximum power that can be introduced but also the distribution of heating within the tissues must be known to arrive at a valid estimate of the general effectiveness of short wave diathermy machines. Obviously a machine which delivers the necessary useful power but which heats fat or other nonconductive tissue excessively, is not a satisfactory machine for the treatment of patients. In fact, the purpose of short wave diathermy, and to be sure, the only justification for its use, is to provide a means whereby heat may be introduced into deep tissue without heating excessively fat and superficial tissues. In an effort to minimize heating of the superficial and fatty tissues, shorter

TABLE 53

EFFECT OF INCREASED POWER INPUT ON TEMPERATURE RISE

Machine	Power Input in Watts per 1000 cc. of thigh	Temperatures and Temperature Rise									
		0 minutes		5 minutes		10 minutes		15 minutes		20 minutes	
		T	ΔT	T	ΔT	T	ΔT	T	ΔT	T	ΔT
		°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
1	48.0	96.8	0.0	101.0	4.2	105.2	8.4	107.2	10.4	106.1	9.3
2	35.3	96.7	0.0	99.6	2.9	102.4	5.7	104.7	8.0	106.0	9.3

and shorter wavelengths and increased air space are being employed by users of the condenser field method of applying high frequency energy for therapeutic purposes. It has been our experience that this objective, namely, the production of heat primarily in conductive and hence vascular tissues, can best be achieved by means of induction heating.

The Council on Physical Therapy of the American Medical Association bases its acceptance of the deep heating ability of a machine on temperature measurements in the thigh of a human subject.[18, 19, 20] It becomes inconvenient and not altogether devoid

[18] Mortimer, B., and Osborne, S. L. Tissue Heating by Short Wave Diathermy. J.A.M.A. 104 1413 1935

[19] Coulter, J. S., and Carter, H. A. Heating of Human Tissues by Short Wave Diathermy. J.A.M.A. 106 2063 1936

[20] Council on Physical Therapy, A.M.A. Apparatus Accepted p. 21. 1940

of the possibility of untoward results to make a routine practice of this method of test Furthermore, although under the conditions of this test a generator may demonstrate adequate deep heating, it cannot be concluded that such generator will be able to produce comparable heating effects under different conditions of application [21] Because of circulation changes, the final tissue temperature at the end of the usual twenty minute period of application cannot be considered as a criterion for classifying short wave diathermy generators By such criterion a machine of high useful power output may be rated lower than one which in reality is less efficient [22] In Table 53 are given the temperatures obtained in the thigh of a subject at five minute intervals with two different power inputs, both of which produced however approximately the same final temperature It is to be noted that the higher power input produced no greater final rise than did the lower but did however produce marked modification in circulation as evidenced by the deviation of the temperature time curve from a straight line

Holmquest and Mittelmann[23] decided to determine whether a physical phantom could be devised which would have approximately the same power absorption as the human thigh and which would also give an indication of the relative heating of conductive and non conductive tissues for various short wave diathermy machines and methods of application The thigh was chosen as the part of the body for which to devise a phantom because of the extensive work already done by various investigators to determine the actual temperature rise in this part of the body for various technics of applying the high frequency energy of short wave diathermy apparatus [24, 25, 26]

[21] Kowarschik J Dosage Measurement in Short Wave Diathermy Arch. Phys Therapy 20 208 1939

[22] Mittelmann E and Holmquest H. J The Useful Power Output of Short Wave Diathermy Apparatus Quart Bull Northwestern University Med School 14 172 1940

[23] Holmquest H. J and Mittelmann E. A Physical Method of Determining the Useful Output of Short Wave Diathermy Apparatus Quarterly Bull Northwestern University Med School 15 255 1941

[24] Mittelmann E and Holmquest H. J The Useful Power Output of

The problem was then to devise a physical phantom which uld have the power absorption of the average living human gh and which would give an indication of the relative heating conductive and non conductive tissues such phantom to be d with a high frequency wattmeter whereby the power absorbed the phantom could be measured

The phantom was constructed as shown in Fig 149 A A and 3 are two glass cylinders which were cemented into a Bakelite e C The dimensions of the component parts and their arrange nt are as indicated It was decided to use 3000 cc of isotonic ine (concentration 85 grams of NaCl per 100 grams of solu n) as the electrolyte within the inner cylinder to represent vascular tissues of the thigh, and a vegetable oil between the er and outer glass cylinders to the same level as the electro-e to represent the subcutaneous fat and other non-conductive nponents of the thigh It was thought that the thickness of oil ployed was too great to represent fairly the subcutaneous fat the average thigh, but after measurements of power absorption the phantom and by the human thigh it was concluded to use phantom as originally devised and as shown in Fig 149 ese investigators admit that subsequent work may suggest nor modifications of the phantom so far as dimensions are ncerned to assure even closer approximation to the average man thigh The measurements of power absorbed by the antom and by the average human thigh for the machines tested d the technics of application employed were sufficiently close r all practical purposes, however, to justify the use of the ggested phantom and associated apparatus for the test of short ve diathermy generators Figure 150 is a diagrammatic draw g of the apparatus as arranged and connected for the test of an

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ort Wave Diathermy Apparatus Quart Bull Northwestern University ed School 14 172 1940

[a] Mortimer B and Osborne S L Tissue Heating by Short Wave athermy J A M A 104 1413 1935

[a] Coulter J S and Carter H A Heating of Human Tissues by Short ave Diathermy J A M A 106 2063 1936

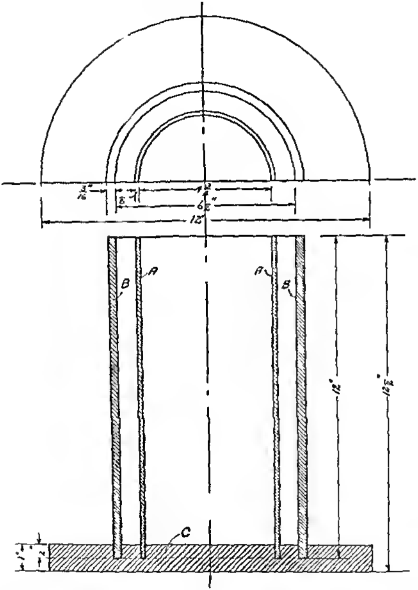

FIG 149 Dimensional drawing of phantom employed in investigation by Holmquest and Mittelmann A A and B B, glass cylinders C, bakelite base into which cylinders are cemented by means of bakelite cement or other electrically non conductive cement which is impervious to electrolyte and oil

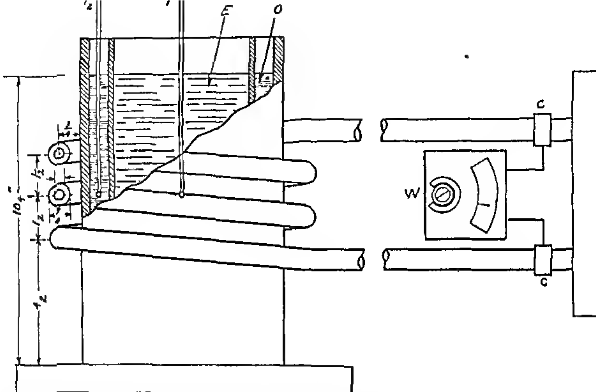

FIG 150 Diagrammatic drawing of phantom and associated apparatus as arranged and connected for test of induction field short wave diathermy generator (Machine 1) E 3000 cc isotonic saline solution (concentration of 85 grams NaCl per 100 grams of solution) O vegetable oil T_1 and T_2 thermometers placed in electrolyte and oil respectively C C coupling condensers for connecting high frequency wattmeter W to cable applicator of diathermy machine

induction type short wave diathermy machine E denotes isotonic saline solution, O, vegetable oil T_1 and T_2 thermometers placed in electrolyte and oil, respectively C C, coupling condensers for connecting wattmeter W The wattmeter was calibrated as described elsewhere The machine under test, designated Machine 1, was adjusted for maximum power absorption by the phantom, and temperature readings in electrolyte and oil were taken every five minutes A twenty minute run was decided upon since that is the time of application used in the tests made on the human thigh, which tests have been previously referred to [27, 28, 29] Before temperature readings were taken, electrolyte and oil were stirred The average power absorption during the twenty minute application was measured by means of the wattmeter

A determination was made of the maximum power that the generator could introduce into the human thigh Five determinations on different subjects were made and the average power absorption computed The number of turns the spacing between turns and the diameter of turns of the cable were kept the same as in the test with the phantom

From the dimensions specific heat, mass, and volume of the electrolyte, the oil, and the glass cylinders, the power input into the phantom was estimated for the final temperature rises obtained in the electrolyte and oil In Table 54 are summarized the various measurements and computations obtained with Machine No 1

In Fig 151 the temperature rises obtained are plotted against time The temperature rise of the electrolyte which simulates vascular and other electrically conductive tissues with respect to electrical conductivity, was greater than that of the surrounding oil representing the subcutaneous fat and other non-conductive tissues of a thigh At the end of the twenty minute run the rise

[27] Mortimer B and Osborne S L Tissue Heating by Short Wave Diathermy J A M A 104 1413 1935

[28] Coulter J S and Carter H A Heating of Human Tissues by Short Wave Diathermy J.A M A 106 2063 1936

[29] Council on Physical Therapy A.M A. Apparatus Accepted p 21 1940

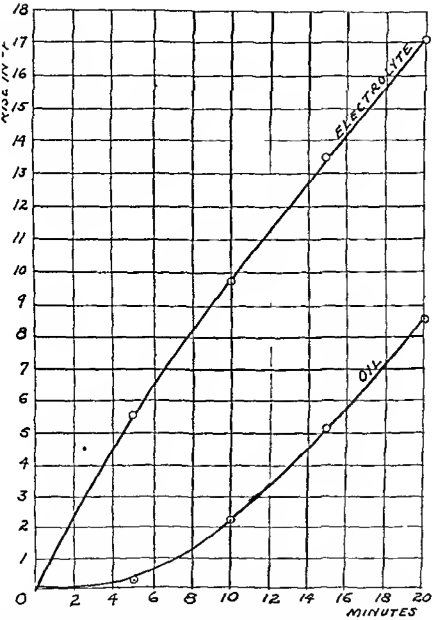

FIG 151 Induct on field—Machine 1 Average temperature r se in phantom for maximum power absorption of 131 watts

in the temperature of the electrolyte was approximately twice that of the oil. The curvature of the temperature rise-time curve for the oil indicates that the rise in temperature of the oil was primarily due to conduction of heat from the electrolyte to the oil and not to the conversion of electrical energy into heat within the oil itself. This also simulates the heating of fat within the living body, for it is only by conduction of heat from the blood and the tissues in which oxidation takes place that fat is warmed.

The close agreement between the maximum power absorption of the phantom and the maximum power it was possible to introduce into an average adult thigh indicates that from an electrical

TABLE 54

INDUCTION FIELD, MACHINE 1

Time (Min.)	T		ΣΔT		Watts			
					Phantom		Thigh	Lamp Load
	T_1	T_2	$\Sigma\Delta T_1$	$\Sigma\Delta T_2$	Measured	Calculated	Measured (Av of 5)	Measured
0	84.0° F	84.0° F	0° F	0° F				
5	89.5	84.3	5.5	0.3				
10	93.7	86.2	9.7	2.2				
15	97.2	89.1	13.2	5.1				
20	101.2	92.5	17.2	8.5	131	128	128.4	202

viewpoint the phantom represents the adult human thigh sufficiently close for the purpose for which the phantom was devised. The calculated power absorption agreed well with the measured power input, but based as it was on certain assumptions as to increase in temperature of the glass cylinders, the calculated power absorption can be considered only an estimate.

The second machine tested was a short wave diathermy machine designed for the use of air-spaced electrodes. Five-inch electrodes were placed on opposite sides of the phantom as indicated in Fig. 152. The procedure of test was similar to that already described.

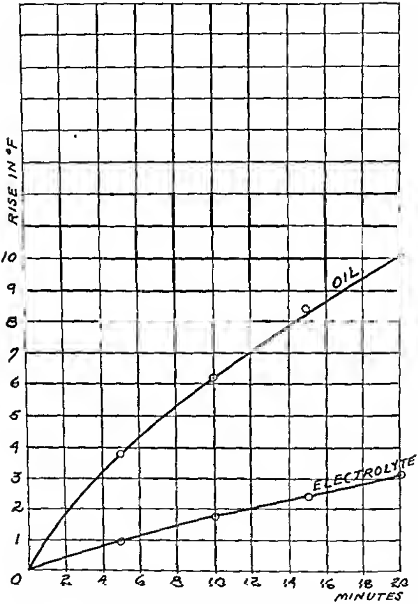

FIG 153 Condenser field—Machine 5 Average temperature rise in phantom for maximum power absorption of 52 watts

of the generation of heat in the body is concerned A point to be noted is that in the case of Machine 5 the maximum power it was capable of introducing into the phantom was 52 watts and into the thigh 54 5 watts, although its maximum available output as measured by a lampload, having its impedance matched to that of the machine, was 375 watts, whereas in the case of Machine 1, 131 watts were introduced into the phantom and 128 4 watts

TABLE 55

CONDENSER FIELD, MACHINE 5

Time (Min)	T		ΣΔT		Watts			
					Phantom		Thigh	Lamp Load
	T_1	T_2	$\Sigma\Delta T_1$	$\Sigma\Delta T_2$	Measured	Calculated	Measured (Av of 5)	Measured
0	74 1° F	74 1° F	0° F	0° F				
5	75 0	77 9	0 9	3 8				
10	75 8	80 3	1 7	6 2				
15	76 5	82 5	2 4	8 4				
20	77 2	84 1	3 1	10 1	52	48	54 5	375

into the thigh although lampload watts were only 202 The ratio of useful power absorbed by thigh or phantom to maximum available power as measured by a matched load, was approximately 0 145 for Machine 5, using condenser electrodes, and 0 65 for Machine 1, using induction coil These results are further confirmation of the previous conclusions that power measurements of output of short wave diathermy generators by means of a lampload are of no value whatsoever as indicators of the amount of power such generators are capable of introducing into a patient

Similar determinations were made of the power output and heating distribution of four additional generators, one utilizing the condenser field and three the induction field The procedure

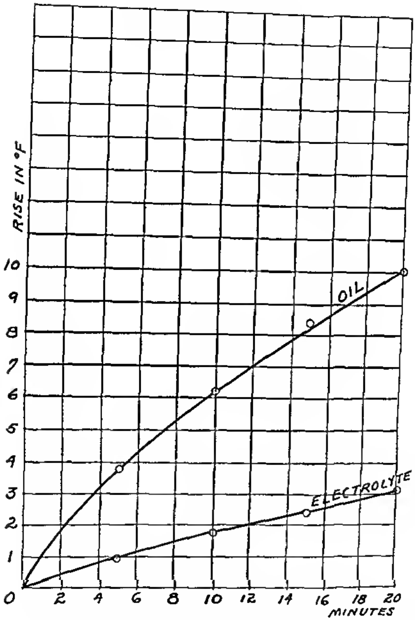

Fig 153 Condenser field—Machine 5 Average temperature rise in phantom for maximum power absorption of 52 watts

of the generation of heat in the body is concerned A point to be noted is that in the case of Machine 5 the maximum power it was capable of introducing into the phantom was 52 watts and into the thigh 54.5 watts, although its maximum available output as measured by a lampload, having its impedance matched to that of the machine, was 375 watts, whereas in the case of Machine 1, 131 watts were introduced into the phantom and 128.4 watts

TABLE 55

CONDENSER FIELD, MACHINE 5

Time (Min)	T		$\Sigma\Delta T$		Watts			
					Phantom		Thigh	Lamp Load
	T_1	T_2	$\Sigma\Delta T_1$	$\Sigma\Delta T_2$	Measured	Calculated	Measured (Av of 5)	Measured
0	74.1° F	74.1° F	0° F	0° F				
5	75.0	77.9	0.9	3.8				
10	75.8	80.3	1.7	6.2				
15	76.5	82.5	2.4	8.4				
20	77.2	84.1	3.1	10.1	52	48	54.5	375

into the thigh although lampload watts were only 202 The ratio of useful power absorbed by thigh or phantom to maximum available power as measured by a matched load, was approximately 0.145 for Machine 5, using condenser electrodes, and 0.65 for Machine 1, using induction coil. These results are further confirmation of the previous conclusions that power measurements of output of short wave diathermy generators by means of a lampload are of no value whatsoever as indicators of the amount of power such generators are capable of introducing into a patient.

Similiar determinations were made of the power output and heating distribution of four additional generators, one utilizing the condenser field and three the induction field The procedure

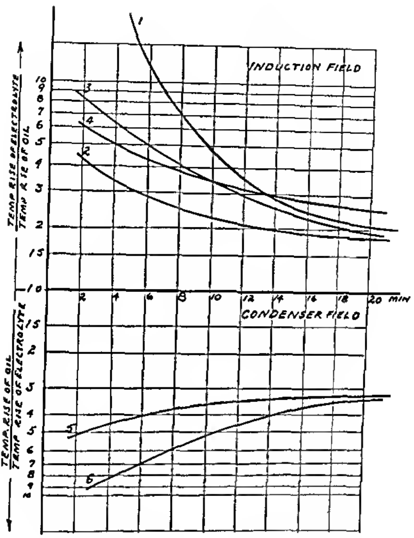

FIG 154 Relative heating of electrolyte and oil by induction and condenser field methods of applying short wave diathermy

of test was as already described The results are summarized in Table 56 For all the machines using the induction field, the rise in temperature of the electrolyte was approximately twice that in the oil, whereas in the case of those machines employing the condenser field the ratio was less than one third In Figure 154

the ratio of temperature rise in electrolyte to that in oil is plotted against time for machines 1 to 4, which use the induction field, and the reverse ratio for machines 5 and 6 with which the condenser field is employed These curves indicate that the final temperature of the electrolyte is under all conditions higher than that of the oil when using the induction field, whereas the reverse is true when using the condenser field

From a consideration of the foregoing data and information,

TABLE 56

SUMMARY OF OBSERVATIONS

Application	Machine	Max Watts Lamp Load	Wave-Length Meters	$\Sigma\Delta T$		$\Sigma\Delta T_e/\Sigma\Delta T_o$	Watts		
							Phantom		Thigh
				$\Sigma\Delta T_e$	$\Sigma\Delta T_o$		Meas'd	Calc	Meas'd
Induction Field	1	202	24	17 2° F	8 5° F	2 02	131	128	128 4
	2	—	25	11 6	6 3	1 84	80	88	75
	3	500	24	*23 4	*9 7	**2 41	—	226	—
	4	350	25	34 3	15 0	2 3	—	250	—
Condenser Field	3	373	11 3	3 1	10 1	0 308	52	48	54 5
	6	—	8	3 0	13 8	0 316	88	76	82 5

* 15 minute application The rest 20 minutes

** See Fig 154 for extrapolation to 20 minutes

one concludes. first, that a phantom of the type described should be used for testing short wave diathermy generators; second, that a short wave diathermy machine to be adequate for the full range of short wave diathermy treatments should he capahle of introducing not less than 100 watts into this phantom; and third, that the rise in temperature of the oil of the phantom should not exceed the rise in temperature of the electrolyte for the same initial temperatures of the electrolyte and oil.

SUMMARY. There are two methods in practice of applying high frequency power to tissue for treatment purposes. one, hy means of the high frequency field such as exists hetween plate electrodes, with or without an air space between electrodes and skin; and the other, hy means of the high frequency magnetic field, which is set up hy the high frequency current flowing through a coil which

is wound around the part to be treated, or wound into a flat "pancake" type coil and placed over the tissues in which it is desired to generate heat.

Much investigative work has been done to determine the heating characteristics of these two methods of application It has been shown that with the high *frequency electric field heating* depends on the specific conductivity of the electrolyte exposed to the field and rises to a maximum for a certain conductivity As the frequency of the field is increased, the conductivity at which maximum heating occurs increases There has been shown to be a linear relationship between frequency and specific conductivity for maximum heating For a frequency of 10 megacycles (wavelength of 30 meters) maximum heating occurs in a NaCl solution having a specific conductivity of 5 47 (in 10^4 ohm^{-1} cms^{-1}), or a concentration of .0045 gram mols per liter or 0263 grams per 100 grams solution [30, 31, 32, 33] Since for dilute solutions conductivity is proportional to concentration, we can determine readily the approximate concentration of NaCl solution in which the rate of heat production would be greatest for various frequencies

Frequency	*Concentration for Maximum Heating*
10,000,000 cycles/sec	.0263 grams/100 grams solution
20,000,000	0526
30,000,000	0789
40,000,000	.1052
50,000,000	1315

The concentration of NaCl solution having the conductivity of blood plasma is 0 85 grams per 100 grams solution In order that heat be produced dominantly in the vascular type of tissue, where heat is normally produced through energy metabolism, a very

[30] Hosmer, Helen Heating Effects Observed in the High Frequency Static Field Science 68 325 1928

[31] McLennan, J C, and Burton, A. C The Heating of Electrolytes in High Frequency Fields Canadian J Research. 3 224 1930

[32] McLennan J C, and Burton, A. C Selective Heating by Short Radio Waves and Its Application to Electrotherapy Canadian J Research. 5 550 1931

[33] DeWalt, K. C A Study of High Frequency Heating Electronics November, 1932

high frequency must be employed. It must not be inferred from the foregoing, however, that, knowing the approximate specific conductivity of various organs in the body, frequencies could be selected to elevate the temperature of these organs without elevating the temperature of other tissues and organs The efficiency of the blood stream in dissipating heat and conveying it to other structures of the body tends to equalize temperatures and hence to prevent such specific heating

But if heat can be generated in the tissues where nature intended it to be generated, namely, the vascular tissues, and so briog about and maintain an active hyperemia, it is obvious that such a method of applying heat for therapeutic purposes should be preferred.

Let us now consider the second method of applying high frequency energy to the tissues of a patient Experiments have been performed showing that the induction field generates heat in an electrolyte in direct proportion to the conductivity of the electrolyte[34, 35] Fig 155 Such a field should produce heat dominantly in vascular tissue Actual measurement of temperatures obtained in the deep tissues of living subjects have confirmed this theoretical deduction[36, 37]

From time to time claims are made for specific biologic and bactericidal effects of various frequencies Careful investigators here and abroad seem today agreed that the only demonstrable effects of short wave diathermy are the production of heat and the physiologic effects that normally follow the production of heat in tissue[38, 39] Hence that method of applying short wave

[34] Merriman, J R., Holmquest, H J, and Osborne, S L A New Method of *Producing Heat in Tissues* The Inductotherm Am Jour Med. Sciences 187 677 1934

[35] Holmquest, H. J, and Marshall, J G Inductothermy Its Physical Basis and *Technique of Application*. Brit Jour Phys Med 4 70 1936

[36] Mortimer, B, and Osborne, S L Tissue Heating by Short Wave Diathermy J A M.A. 104 1413 1935

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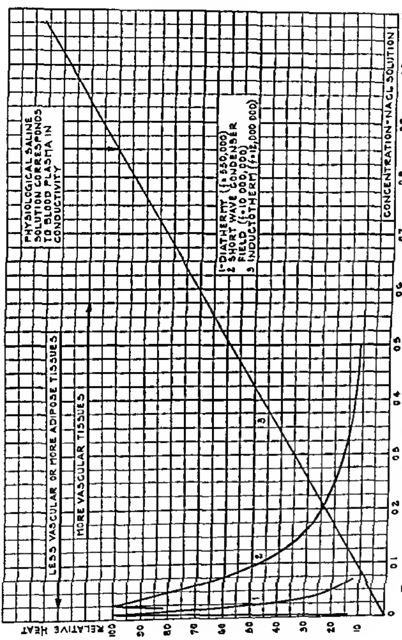

FIG 155 Heating of an electrolyte by conventional diathermy (1), by the high frequency electric field (2), and by the induction field (3)

diathermy which develops heat primarily where oxidation produces it naturally in the human body, thereby inducing and maintaining an active hyperemia and permitting the warmed circulating blood to convey heat to other tissues, would seem to be the preferred method of application for treatment of all conditions that might be benefited by such therapy.

Briefly, the physical and physiologic reasons for applying short wave diathermy by the induction method are:

(1) The induction field generates heat in an electrolyte in direct proportion to its conductivity; and hence, when human tissues are subjected to the high frequency induction field, heat is dominantly produced in the vascular type of tissue rather than in fat or other non-conductive or poorly conductive tissues.

(2) It is in the vascular tissues that the living body normally produces heat, and hence heating by the induction field simulates the normal production of heat, at least so far as the site of the generation of heat is concerned

(3) It is through the agency of the blood stream that the living body combats infection, eliminates waste products, relieves congestion, and brings about repair of tissue.

(4) The induction and maintenance of an active hyperemia, as a consequence of the generation of heat by the induction field in vascular tissue, assists the body, therefore, in combating infection, eliminating waste products, relieving congestion, and bringing about repair of injured tissues.

(5) It follows that the use of the induction field is indicated in all conditions that can be benefited by the production and maintenance of an active hyperemia

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PART D HIGH FREQUENCY CURRENTS

SECTION THREE TECHNIC OF LOCAL APPLICATION

I INTRODUCTION By local application is meant the local or regional application of high frequency electric energy for the purpose of generating heat in a local or regional part of the body, in contradistinction to general application for the purpose of elevating the temperature of the entire body This latter application will be discussed in a subsequent section

The local application of high frequency currents and fields may be for either medical or surgical effects, the effect obtained depending upon the energy input per unit volume of tissue per unit time An application which does not produce destruction of tissue cells or impairment of their function is termed *Medical Diathermy*, whereas, if the application is such that destruction is obtained, it is termed *Surgical Diathermy*

For either application, damped or undamped waves may be employed The application of the spark gap oscillator, generating a succession of damped waves for either medical or surgical purposes, is known as *Conventional Diathermy* The application of high frequency currents generated by a vacuum tube oscillator, is referred to as *Short Wave Diathermy* Conventional diathermy is being rapidly replaced by short wave diathermy However, conventional diathermy is still being used by some For that reason, the technic to be followed in administering treatment by this method has been included in the following discussion

II GENERAL PRINCIPLES OF TECHNIC

1 Diathermy should never be applied over areas of the body where injury has damaged the sensory nerves Over such areas heat sensation may be entirely absent, or the patient may not be able to discriminate readily variations in heat intensity *The ability to sense heat must be unimpaired in patients to whom diathermy is to be administered*

2 During the first treatment it is advisable to keep well below the patient's maximum heat tolerance In this way the confidence

of the patient is secured, and, in addition, any unusual reaction to heat may be noted

3. The patient should be informed that no sensation other than that of a comfortable degree of heat should be experienced If other effects than a comfortable diffused heating are present, such as a so-called "hot spot," a minute prickling sensation, or an uncomfortable heat, the patient must be warned to notify the operator immediately.

4. The only safe guide for dosage is the patient's tolerance The tolerance to heat must never be exceeded.

5. Patients must be warned against disturbing the electrodes in any manner whatsoever, once they are applied

6. While it is not necessary for the operator to be with the patient throughout the entire treatment, it is essential that the patient should be under supervision. In some instances, patients are provided with a switch-cord, permitting them to terminate the treatment if too much heat is felt beneath the electrode or other untoward effects are experienced. Such a device should not be necessary, however, if proper techoic is followed

7. The generator should be placed beyond the reach of the patient, and if not, he should be warned against touching any part of the apparatus while uodergoing treatment. He should also be warned against making contact with metal partitioos, wall switches, and all other grounded objects and current-carrying conductors

8. Metal beds or metal treatment tables should not be used for patients duriog diathermy application Should their use be unavoidable, special precautions must be taken to prevent contact of either patient or apparatus with the metal Treatment tables for such applications should be of wood

9. Before starting treatment, all cootrols should be at zero.

10 After the generator has been energized, the intensity control, which determioes the rate of energy input into the tissues, should be gradually iocreased to obtain the desired intensity. Only when it is impossible to obtain the desired current by means of the intensity control, should the spark-gap distance be increased, this applies only of course in the case of a conventional diathermy apparatus.

11. Increase the current intensity gradually when using the vacuum tube as well as the spark-gap oscillator, reaching the desired maximum current intensity in approximately five minutes

12. At the termination of the treatment, all controls should be brought to zero before turning off the main switch In case of an emergency, however, the main switch should be turned off without hesitation.

III. CONVENTIONAL DIATHERMY. There are three general methods of application: direct, indirect, and autocondensation

DIRECT

Electrodes The electrodes for conventional diathermy applications may be either of bare metal applied directly over the skin, or of some absorbent material such as cellucotton, canton flannel, or orthopedic felt, which is made conductive by saturating in twenty per cent sodium chloride solution, or the electrode may be a vessel containing a conductive solution into which the part is immersed, thus serving as one of the electrodes In our opinion, the electrodes of choice are those of metal applied directly to the skin We shall, therefore, confine our technic to this type of electrode However, the absorbent type of electrode may be preferred by some If such electrodes are used, they are applied in the same manner as the absorbent electrodes for direct current applications

Metal electrodes are made of a metal alloy and must be quite pliable We have found the thickness of 0 016 inch (25 gauge) to be quite satisfactory This is sometimes known as medium foil, and is usually sold by the pound This foil can be readily cut into any desired shape It is advisable to prepare a complete set of electrodes such as that illustrated in Fig 156

The metal electrode should be so cut that all edges are clean and smooth and not left jagged All corners must be rounded and not square. The edges should be rounded to minimize concentration of current at the edge of the electrode When cutting the electrode, leave a projecting tab for the purpose of attaching the patient's conducting cord By means of a 12 inch roller, approximately one inch in diameter, such as a metal autocondensation

handle or a 12 inch length of a broom handle the electrode, prior *to every application, should be rolled* smooth and entirely free of rucks Creases in the electrode must be eliminated When the electrode needs shaping to conform to the contour of the part under treatment, the moulding should be done with a minimum of electrode handling Once the electrode is finally placed in posi-

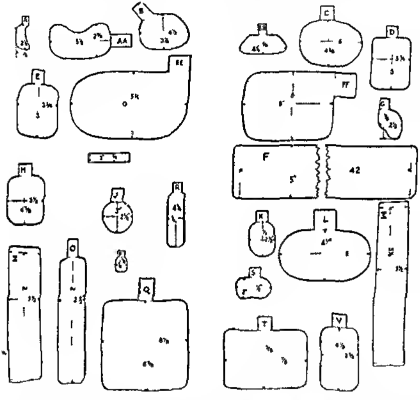


FIG 156 Suggested set of electrodes for conventional diathermy application

tion, it should be held at its center lightly in contact with the skin It should be free from pressure at the edges until held in position by means of a sandbag or bandage It is very important *that the edges of the electrode do not press into the skin* The pressing into the skin of a sharp edge of an electrode is the cause of the so called "edge effects" and edge burns It is necessary to secure good contact but uneven contact must be carefully avoided,

particularly at the edges. When bandages are used to retain electrodes in position, they must not be applied too tightly. Otherwise circulation might be retarded, thus defeating the purpose of administering treatment, namely, to promote an active hyperemia

Electrodes should be warmed before applying to the patient to avoid any disagreeable sensation from contact with the cold metal Some operators prefer to apply a conductive jelly on electrodes made of metal foil to minimize electrode discomfort, but in the clinic at Northwestern University it has not been our custom to use such lubricants However, with certain types of spark-gap oscillators it may be desirable to use some conductive compound on the electrodes

With the metal mesh electrode, a conductive compound must always be used Soap lather has been widely used for this purpose, but such a medium is an extremely poor conductor and should not be employed

Conducting cords Such cords are used to conduct the current from the high frequency apparatus to the electrodes To prevent the weight of the cord from pulling on the electrode and eventually displacing it, the weight of the cord should be supported by tucking a section of it under the mattress or under the pillow of the patient's treatment table, or by placing a sandbag over it to hold the cord in such a manner as to prevent any pull on the electrode

Specific Technics of Application

Double Plate, Through and Through, or Transverse Method. The part of the body to be treated is sandwiched directly between two electrodes Fig 157 The two electrodes may be equal in size, or one may be larger than the other.

Electrodes having the same area are employed in an attempt to produce heat to the same degree throughout all of the tissues sandwiched between the two electrodes However, because of the heterogeneity of tissue from an electrical viewpoint, and because of the spreading out of the current flow from electrode to electrode even in homogeneous tissue, a uniform rate of heat production per

unit volume of the tissues between the electrodes cannot be achieved Electrodes of equal area, however, assure equal current densities at both contact surfaces Both electrodes, when of equal size, are considered active electrodes

When it is desired to produce heat at a greater rate near one electrode than at the other, electrodes of unequal area are employed The current density will be greatest beneath the smaller

FIG 157 Double Plate or Transverse Method of Application

electrode Consequently the rate of heat production will be greater near this electrode Hence, if there is a difference in the areas of the two electrodes, heat will be felt primarily in the region of the smaller one The greater the difference in area the greater will be the relative heating in the region of the smaller electrode The smaller electrode is therefore referred to as the active electrode, the larger electrode being referred to as the dispersive electrode

When using the double plate technic, it is important that the current path through the tissues sandwiched between the plates,

be shorter than the current path over the skin from the edge of one electrode to the edge of the other. Should the electrodes be so applied that the current path over the surface from edge to edge of opposing electrodes, presents less resistance to the flow of current than the deeper tissues, an excessive portion of the total current will flow through this path with an inadequate flow of current through the remainder of the tissues. The result is an excessive concentration of current flow at the opposing edges of the electrodes with consequent marked discomfort and burning, commonly known as *edge effect.*

The opposing edges of the electrodes must be equidistant from each other insofar as is possible. If the edges are not equidistant, there will be a coocentration of current and hence of heat production where the edges are closest together. It is important when treating a tapering part, such as a thigh, that the electrode be of such configuration and so applied that as near a uniform distribution of current as practicable be secured. To achieve uniform distribution of current through a tapering or conical volume such as a thigh, the opposiog electrodes must of necessity be wedge-shaped in that their width at the smaller diameter of the thigh be less than their width at the larger diameter. Their relative widths should be such that when the electrodes are applied to the thigh their opposing edges are equidistant.

Plate-and-Cuff or Longitudinal Method. This technic is used principally for such joiots as the wrist, hand, ankle, and foot. Figs. 158 and 159. One electrode is a rectangular metal plate approximately 10 inches by 8 inches. The actual size is determined by the size of the hand or the foot of the patient If a joint such as an ankle is to be treated, the entire foot must be in contact with the metal plate. The other electrode consists of a metal cuff about 3 inches wide and of sufficient length to encircle completely the calf of the leg. When electrodes are properly applied, heat will be felt at the ankle joint and not in the region of either electrode.

Double Cuff Method This method is used for the treatment of such joints as the elbow and knee. The cuffs are 3 inches wide, and of sufficient length to encircle completely the arm or leg and

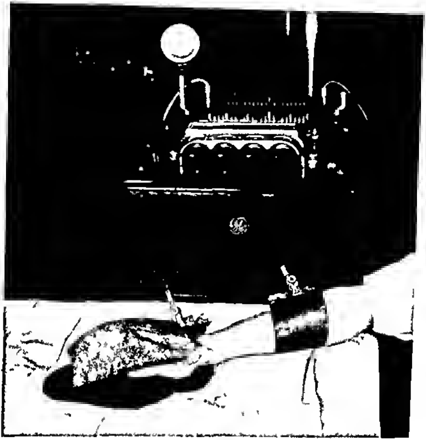


Fig 158 Plate and Cuff Method Treatment of wrist

to permit clamping together about 1½ inches of the ends of the cuff. The ends are folded over once to secure and maintain adequate contact between cuff and skin surface. An electrode clip is clamped over the fold to secure the electrode and to provide an electrical connection.

The joint to be treated should be equidistant from the two cuffs which encircle the arm or leg When the double cuff method is used, the arm or leg under treatment should be fully extended If the joint is flexed, the current density will be greater through the tissues forming the shorter path, with consequent excessive heating in those tissues Cuffs should completely, and not par-

FIG 159 Plate and Cuff Method Treatment of ankle.

tially, encircle the arm or leg The cuffs should be placed as far apart as the anatomical configuration of the part to be treated will permit.

Special Electrodes Fenestrated metal foil electrodes with a sinuated periphery were made for the application of conventional diathermy to the entire trunk of a patient to produce artificial fever These were known as *Neymann Electrodes*. Modifications of these electrodes have been used for the application of diathermy to the head and face as well as to other parts where application of the ordinary foil electrode is difficult. Novak devised a set of electrodes of this type for applying diathermy to the region of the head and face They are illustrated in Fig 160.

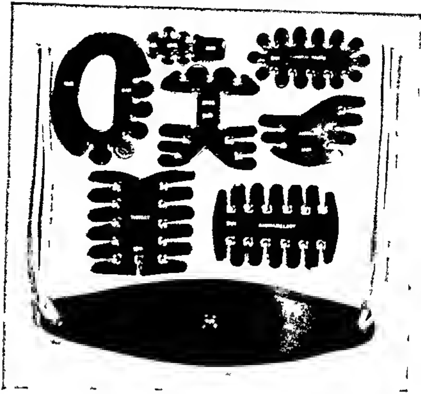
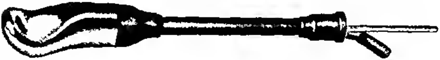


FIG 160 Novak fenestrated electrodes for the application of conventional diathermy to head and face

Various *orificial electrodes* have been devised for the application of diathermy directly to the vagina, cervix, rectum, and prostate Fig 161 These electrodes are of metal and usually plated with a non-corroding metal Some of the electrodes are provided with a thermometer which measures the surface temperature of the tissues undergoing treatment When using such electrodes, it must not be assumed that the temperature of the deeper tissues is the temperature indicated by the thermometer

Dosage By dosage is meant the total input of energy The total input of energy into a given load having a constant effective resistance, is determined by the current flow and the time that current flows In administering diathermy it is therefore necessary to consider both current flow and duration of application

The same total power input can be achieved with either a low current flow and a long time of application, or a high current flow and a short time of application Unfortunately, this fact has not been given the consideration it merits It has been our observation



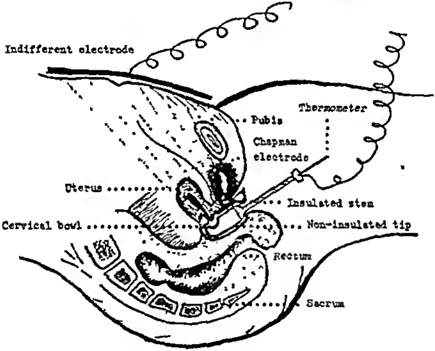


FIG 161 (a) Chapman Vaginal Electrode Cross section of the female pelvis showing Chapman Electrode in position (From Chapman Am Jour Phys Therapy, May, 1927)

that, from a therapeutic viewpoint, long applications at relatively low intensities are more effective

The milliamperage read on the meter indicates the current flowing through the tissues, but does not indicate the power absorption in the tissues Only when the effective resistance of the tissues remains constant, can the current reading be taken

as an index of the power absorption, and then the power absorp tion will be proportional to the square of the current That is to say, if the effective resistance remains constant, doubling the

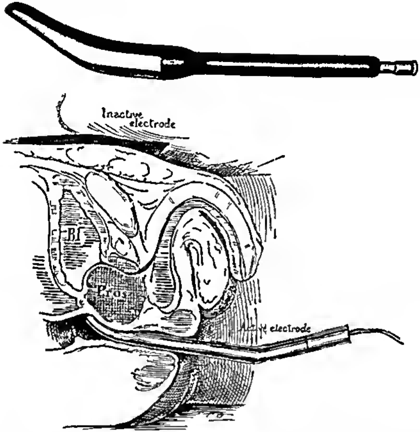


Fig 161 (b) Prostatic electrode Cross section of the male pelvis illustrating the application of the prostatic electrode (From Corbus and O Connor Diathermy in the Treatment of Genito Urinary Diseases Courtesy Bruce Publishing Company)

current flow quadruples the power input into the tissues If the frequency of the current should be changed, the effective resistance of the tissues will be changed As the frequency increases the proportion of the total current that produces heat becomes less Therefore, a milliampere meter is useful only when the same

generator, having a constant frequency, is employed. It can be shown that if applications are given consecutively to the same subject with different generatnrs of different design, without disturbing the electrodes and with current intensity determined

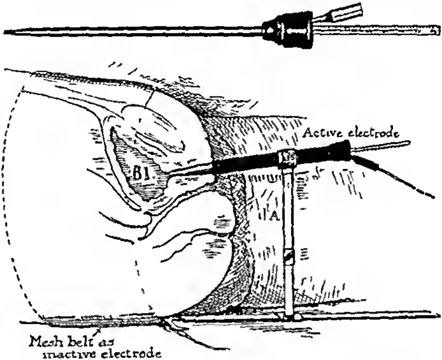


FIG 161 (c) Corbus Thermophore Cross section of the female pelvis illustrating the Corbus Thermophore as used in the treatment of diseases of the female urethra (From Corbus and O'Connor. Diathermy in the Treatment of Genito-Urinary Diseases Courtesy Bruce Publishing Company)

by the tolerance of the subject, the meter reading will be different for the different generators Hence, the meter reading merely serves as an aid in duplicating treatments when the same generator is used

The only safe guide for current intensity is the patient's tolerance. *This must never be exceeded.* The manufacturer should state the current density, i e, milliamperes per square inch, that may be used as a guide for treatment with his particular generator. For the various generators available, this ranges from

30 to 100 ma per square inch of electrode surface Total current is always computed in terms of the smaller of the two electrodes, being equal to the current density in ma per square inch times the area of that electrode Patients with much adipose tissue will not tolerate a given current density as well as the average individual Such individuals have a low current tolerance Certain pathology may also limit the amount of current that a patient can tolerate

When administering diathermy, the current intensity should be *gradually* increased so that skin resistance is gradually reduced and the maximum current intensity, when finally reached, is readily tolerated When using cuff electrodes, *tolerance of the patient* alone is the only guide to proper current intensity For with such electrodes the current flow is not uniform over the surface of the electrodes, and hence computation of safe current intensity cannot be made on the basis of so many ma per square inch of electrode surface

The duration of a treatment usually varies from twenty to forty minutes However, it is doubtful whether a treatment of such short duration is most effective therapeutically The duration and the intensity of the treatment should be determined by the pathology it is desired to influence For certain pathologies, short treatments given at definite intervals throughout the day may be indicated, while for other pathologies, long periods of low intensity treatment may be more effective

Specific Principles of Technic. In the application of conventional diathermy, certain specific principles of technic should be carefully observed, in addition to the general principles governing the technical application of high frequency currents and fields which were discussed in the general introduction of this section These specific principles are:

1. The skin should be examined for skin abrasions or pustular eruptions, and if present, should be covered with adhesive tape

2. The electrodes should be applied according to the technic already described, and the proper milliammeter scale selected for the range of current to be used

3. After the electrodes have been applied, the line switch is

closed and the spark gaps gradually opened The spark gaps should be operated with minimum spacing Too wide a gap will produce the so-called "faradic" sensation

4 The milliamperage should always be increased slowly, the required current intensity being reached in about five minutes

5 When it is necessary to increase the current, do so by means of the intensity control or other controls that may be provided for that purpose Do not open the spark gaps further, however, unless the other means of increasing the current flow are incapable of giving the desired current

6 If dry metal electrodes give discomfort to certain individuals, the use of a good conducting compound is indicated

INDIRECT This method of treatment was developed because limitations of generators made it impossible to treat certain regions of the body Indirect diathermy produces merely superficial heating and counter irritation It is administered in one of two ways

1 The patient is seated and holds an autocondensation metal handle, which is connected to one terminal of the machine A so called hand electrode is applied to the wrist of the operator and connected to the other machine terminal An alternate technic is to have the patient lie in the supine position on an autocondensation cushion, which is connected to the generator The patient is connected to the other terminal by means of the autocondensation handle, which he holds In either technic, the operator places his hand on the surface to be treated, and then the main switch is turned on *The hand of the operator must not be removed from the patient while the current is on Otherwise, an arc would be established between the operator's hand and the patient* The current is increased until tolerance is reached The operator's hand is kept in motion, giving massage at the same time heat is being generated within the patient's tissues *When necessary to terminate the treatment, the current must be turned off before the operator's hand is removed from the patient*

2 Indirect diathermy may be given also by means of non vacuum or vacuum glass electrodes The glass electrodes are made in various shapes for both surface and orificial applications

Fig 162 a shows a vacuum electrode, coated internally with silver deposition, with insulated handle, and provided with a connection ring for making contact with the conducting cord from a diathermy machine If not provided with an insulated handle as an integral part of the electrode, a separate insulating handle with a clamp to hold the electrode must be used by the operator when

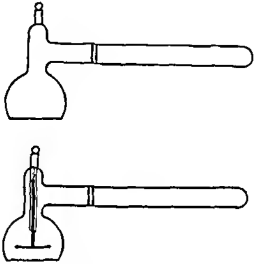


Fig 162 (a) Non vacuum electrode
(b) Vacuum electrode

applying high frequency energy A vacuum electrode of the condenser type is shown in Fig 162 b, provided with an insulated handle Connection with the metal plate of the electrode is made by means of the connection ring as shown in the figure The metal plate and the surface of the patient's skin constitute the plates of a condenser, the dielectric of which is the vacuum between the plate and the flat glass surface together with the glass itself The electrode is connected to the high voltage terminal of the generator According to the degree of heat required it may or may not be necessary to ground the remaining terminal When only one terminal is used, the application is called *monopolar* Grounding the other terminal decreases the impedance to the flow of current, and con

sequently for the same voltage a greater current flow results.

If the patient is lying on an autocnndensation cushion and is connected to the generator as previously nutlined, the glass electrode can he applied to the patient withnut any connection to the machine. Actually the electrode is capacitively grounded through the operator. Care must be taken tn have the current switched off, however, hefore applying or removing the electrode. Before treatment, the skin over which the electrode is to he moved should he dusted with talcum powder. Without talcum powder, the electrode cannot he moved readily at a uniform rate over the surface.

To produce counter-irritation, apply a thin layer of towelling over the area, and then make the electrode application. The thickness of the towel will determine the length of the spark discharge. These discharges produce counter-irritation. Care must he taken to keep the electrode in motion; otherwise, a burn may occur.

In our npinion, indirect diathermy is nf little, if of any, value. However, many clinicians still use it and claim excellent therapeutic results from its use. For a resume of its field of application, the reader should consult Kovacs' excellent book.[1]

AUTOCONDENSATION. According to Kovacs,[1] autocondensation is a modified form of general diathermy. There are two types of autocondensation cushions in use. One consists of a metal plate, approximately 72 inches by 30 inches, over which is placed a 4 inch layer of silk floss, the entire cushion including the plate being covered with a tufted leather casing. When a patient is lying on the autocondensation cushion, the metal electrode forms one plate, the silk floss the dielectric, and the patient the other plate of a condenser. The nther type of cushion consists of a metal plate covered with an insulating fiber material about ½ inch thick. This cushion is hinged so that treatment may be given in the sitting or supine position. The type of cushion best suited for this form of therapy is problematical. Each type bas its advocates.

The cushion is connected tn the high voltage terminal of the

[1] Kovacs, Richard. Electrotherapy and Light Therapy, Fourth Edition. Lea and Febiger, Philadelphia, 1942

generator. The patient lies on the cushion with his head well supported by a pillow. The arms are flexed at the elbows to a right angle. An autocondensation metal handle, connected to the remaining terminal, is held with the hands separated as far as possible The metal handle rests on a pillow, placed on the chest of the patient to provide a support. After the current is switched on, no one should be permitted to touch any part of the patient or a spark sufficient to cause a burn may be established between the patient and the person making the contact The current intensity employed usually ranges from 500 to 1200 ma The treatment is given for thirty to forty-five minutes For evaluation of this treatment see Kovacs [2]

IV. Short Wave Diathermy. As already discussed under the fundamentals of high frequency currents, the development of the thermionic vacuum tube made possible the generation of currents of much higher frequency than those employed in conventional diathermy, and consequently made possible modification in methods of applying high frequency energy for medical purposes The frequencies employed in short wave diathermy range from 10,000,000 to 100,000,000 cycles per second, the frequency employed in any given application being that best suited for the transfer of energy to the patient for the technic used The range in wavelength, corresponding to the frequency range of 10,000,000 to 100,000,000 cycles per second, is 30 to 3 meters

The methods in common use of introducing high frequency electric energy into tissue for the purpose of generating heat, fall into two distinct classifications, namely· one, the use of a high frequency electric field (the so-called condenser field), and two, the use of a high frequency induction field The electrodes employed in short wave diathermy are different from those used in conventional diathermy. As already explained, conventional diathermy is applied by means of bare metal electrodes in direct contact with the skin With short wave diathermy, on the other hand, insulated metal electrodes are employed It is true that bare metal electrodes can be used, but because of the definite

[2] Kovacs, Richard Electrotherapy and Light Therapy, Fourth Edition Lea and Febiger, Philadelphia, 1942

danger of burning the patient with such electrodes, they should not be employed.

HIGH FREQUENCY ELECTRIC FIELD High frequency energy may be applied to tissue by placing the tissues to be heated between plates on which a high frequency potential is impressed The high frequency electric field generates heat in the tissues

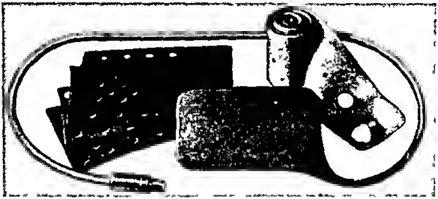


FIG 163 Pad electrode for short wave diathermy

The heat developed results from resistance and dielectric hysteresis losses within the tissues The relative heating of electrolytes of various concentrations by electric fields of different frequencies has been discussed in Section Two

Electrodes The electrodes used with the high frequency electric field, or the *condenser field* as it is more popularly known, consist of *pad electrodes*, *cuff electrodes*, and *air-spaced electrodes*

A pad electrode consists of a flexible piece of metal vulcanized between two layers of rubber, making a total electrode thickness of approximately ⅛ inch. Such electrodes vary both in size and shape They are known as *pad electrodes* by some, and as *condenser electrodes* by others Fig 163 A long insulated conducting lead is attached to the electrode for making connection to the short wave generator

Cuff electrodes are nothing but pad electrodes of such length and width that they may be applied as cuffs, completely encircling a region of the body They are employed chiefly for the treatment

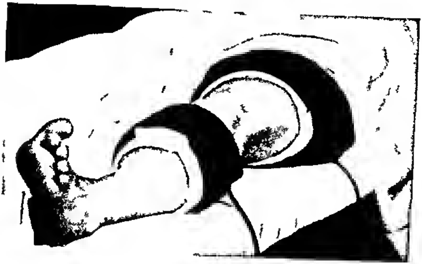


FIG 164 Cuff electrodes

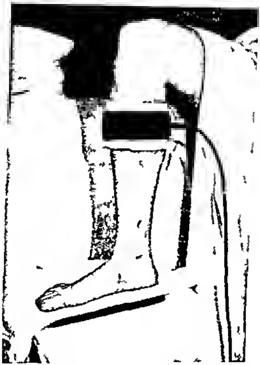


FIG. 165 Application of cuff and pad for treatment of the ankle (From Krusen Physical Medicine Courtesy W B Saunders Co)

of joints Fig 164 A pad electrode and a cuff electrode are occasionally used in combination Fig 165

One type of air spaced electrode is made of a metal plate placed between two thick layers of rubber or other insulating

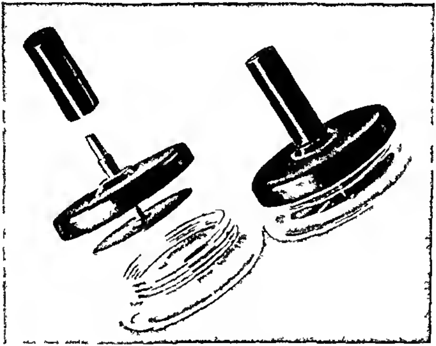


Fig 166 Air spaced electrode

material and may or may not be flexible The electrode is provided with an adjustable guard so that the air space between tissue surface and electrode may be maintained at a given value Such electrodes vary in shape and size Another type of air spaced electrode consists of an appropriately shaped glass or plastic vessel to serve as an insulator and spacer and a rigid metal plate The plate is movable within the cylindrical vessel, this enables the operator to adjust the distance between the metal plate and the skin For different machines different spacings may be required Fig 166 Electrodes of this type dispense with the necessity of using felt or towelling as spacers since the proper spacing is provided by the air gap Hence these electrodes are called air spaced electrodes

Various adaptations of the type of electrodes discussed in the foregoing paragraphs have been devised for orificial application Such electrodes are used with a pad, a cuff, or a large air-spaced electrode as the dispersive electrode We are not convinced that such highly localized orificial treatment is either necessary or desirable. *In our opinion generalized pelvic heating is just as effective ond probably preferable for the treatment of vaginal, rectal, and prostotic conditions.*

Pads, cuffs, and the cuff and pad electrodes are applied in the same manner as the bare metal plates, cuffs, and plate and cuff electrodes for conventional diathermy, with the exception that an appropriate thickness of felt or bath towelling is placed between the skin surface and the rubber surface of the electrodes. The proper thickness of the felt, or other dielectric material that will assure satisfactory operation, will vary with different generators, and therefore should be specified by the manufacturer. Both pads and cuffs have conducting leads attached so that they may be connected to the generator.

Specific Technic of Applicotion

1. Double Pads. (Through and Through Application) The pads may be of the same or of dissimilar area When they are of the same area, the current density in the tissues adjacent to the electrodes will be the same If it is desired to generate heat at a greater rate in the tissues near one electrode, an electrode smaller in area is placed over that region This electrode is designated the *active* electrode The larger electrode is known as the *dispersive* electrode The rules outlined for the application of conventional diathermy, which pertain to the relationship of the current path through the tissues between the electrodes to the current path over the surface from the edge of one electrode to the other, must be observed Furthermore, it must be kept in mind that with the much higher frequencies used in short wave diathermy, current leakage occurs more readily. In fact, current paths which conduct but little current at the frequencies employed in conventional diathermy will conduct appreciable currents at the frequencies

used in short wave diathermy, as was explained in the section dealing with the physics of high frequency currents.

Before application of the electrodes, a towel one layer thick is applied over the area to be treated. The proper thickness of spacing is then applied over the towel. Information on the dielectric

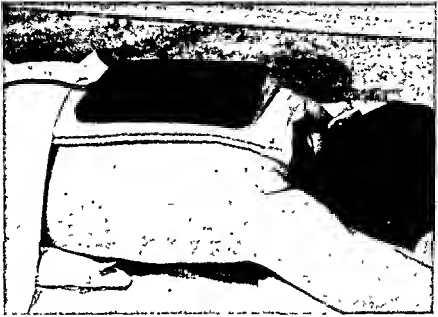


Fig. 167. Application of pad electrodes to the dorsal spine. (From Krusen: Physical Medicine. Courtesy W. B. Saunders Co)

material and the appropriate thickness to be used for best operation of a generator should, as already stated, be provided by the manufacturer and the user of such apparatus should carefully follow these recommendations.

The electrodes are held in place either by an elastic bandage or by a sandbag. As with conventional diathermy, care must be taken to prevent the edges from digging into the tissues; and also, contact between electrode assembly and skin must not be too tight. Fig. 167.

Frontal Sinus. An active electrode, approximately 2 by 4½ inches, is placed over the region of the frontal sinus, with a towel of appropriate thickness between it and the skin, and held in place by a suitable bandage. A dispersive electrode, approximately 5½ by 8½ inches, is placed over the upper dorsal spine, with a towel of appropriate thickness between it and the skin, and held in place with an elastic bandage.

Antrum, Temporomandibular Joint, Mandible, and Throat. The method is similar to that described for the frontal sinus, with the active electrode placed over the part to be treated. The same principles of obtaining concentration of heat may be followed in applying the condenser electrodes with the short wave apparatus as are followed when applying the metal plate electrodes of conventional diathermy, except that with short wave diathermy it is not necessary to be so exacting

Ears. Pad electrodes, approximately 4 by 7½ inches, are placed over each ear, with one or more towels between them and the skin, and held in place with an elastic bandage.

Spine (Cervical). Lateral Method. Pad electrodes, approximately 2 by 4½ inches, are placed on the lateral aspects of the neck, with a towel between them and the skin, and held in place with an elastic bandage.

Anteroposterior Method. With the patient lying on his back, a pad electrode, approximately 4 by 7½ inches, is placed posteriorly over the cervical spine, with a towel between it and the skin The electrode is held in place by a rubber sponge placed between it and the pillow. A dispersive electrode, approximately 5½ by 8½ inches, is placed over the upper anterior chest, with a towel under it, and held in place by a sandbag

Spine (Dorsal). With the patient lying on his back, a pad electrode, approximately 5½ by 8½ inches, is placed under the part of the dorsal spine to be treated, with a towel between it and the skin The dispersive electrode, approximately 12 by 15 inches, is placed over the front of the trunk, with a towel between it and the skin, and held in place by sandbags

Lumbosacral and Sacro-Iliac Regions. The application for

these regions is the same as for the dorsal spine, except that the active electrode, approximately 5½ by 8½ inches in dimension, is placed under the region to be treated.

Shoulder. With the patient lying on his back, a compression bladder, slightly inflated, is placed under the shoulder to be treated to hold the electrode, about 4 by 7½ inches, in good contact. A second electrode of the same size is applied over the anterior surface of the shoulder, with a towel intervening, and held in place by means of a sandbag.

Subdeltoid. With the patient sitting, an active electrode, approximately 4 by 7½ inches, is placed over the deltoid muscle, with a towel between it and the skin, and the electrode held in position by an elastic bandage. A dispersive electrode, approximately 12 by 15 inches, is placed under the opposite arm, over the lateral surface of the chest, and held in place by a bandage

Elbow. Two electrodes of the same size, approximately 4 by 7½ inches, are used. The forearm is extended and supinated. One electrode is placed over the biceps and the other under the extensor surface of the forearm. Towels of appropriate thickness should be interposed between the electrodes and the skin. The electrodes are held in place by a bandage.

Wrist and Hand An active electrode, approximately 2 by 4½ inches or 4 by 7½ inches, is placed over the wrist, a towel between it and the skin, and held in place by a bandage. A dispersive electrode, approximately 12 by 15 inches, is placed on the back, with towels interposed between it and the skin, and held in place by a bandage.

Chest or Abdomen The area to be treated is sandwiched between two electrodes, with towels interposed between them and the skin. With the patient lying on a treatment table, the under electrode is held in place by the patient's weight and the upper one by sandbags The electrodes usually used are two of equal size, either approximately 5½ by 8½ inches, or 12 by 15 inches, or an active electrode 5½ by 8½ inches, and a dispersive one 12 by 15 inches.

Hip. Pad electrodes, approximately 5½ by 8 inches, are placed

anterior and posterior to the hip joint, with the patient lying on his back. Towels are interposed between the electrodes and the skin. The anterior electrode is held in place by a sandbag.

Knee. Two electrodes, approximately 4 by 7½ inches, are placed on the lateral and mesial surfaces of the knee joint, with the patient lying on his back on a treatment table The knee should be slightly flexed and supported by a pillow. Towels are interposed between the electrodes and the skin The electrodes are held in place by an elastic bandage.

Ankle and Foot. With the patient sitting on a chair, his foot is placed on an electrode, approximately 4 by 7½ inches, with a towel between it and the sole of his foot. Another electrode of the same size, with a towel between it and the skin, is held in place over the calf by means of a woven elastic bandage

2 *Plate and Cuff (Longitudinal Method).* This technic is used for the treatment of a wrist, ankle, or specific regions of the foot and hand The most fleshy part of the forearm or lower leg is encircled by a cuff, with proper spacing between the electrode and the skin When it is desired to heat the wrist, the hand is placed, palm down, on a pad electrode with the necessary spacing between the electrode and the skin surface. Similarly, the foot is placed on a pad electrode when treatment is to be given to the ankle joint. The cuff electrode is bound and retained in position by an elastic bandage, and a sandbag is placed on the band or foot of the patient to maintain proper contact of hand or foot with the pad electrode If only a region of the hand or foot is to be treated, that particular region of the hand and foot alone should make contact with the pad electrode A cuff and pad application was illustrated in Fig 165

3. *Double Cuffs.* This technic is used for the treatment of the elbow and the knee The technic of application is illustrated in Fig 164 It is important, as pointed out in the section on conventional diathermy, that the arms and legs be kept fully extended to avoid excessive heating along the inner surface of the joint.

4 *Air-spaced Electrodes.* These electrodes are applied in exactly the same manner for the treatment of various parts of the body

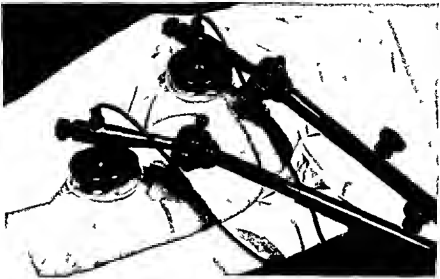


FIG 168 Air spaced electrodes within glass containers.

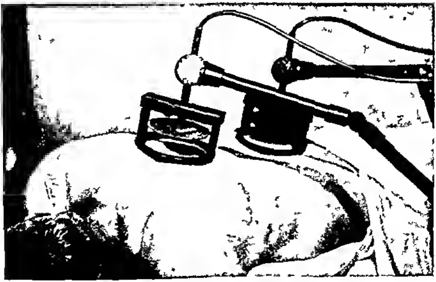


FIG 169 Air spaced electrodes Plate covered with insulation and provided with an adjustable spacer

as are the pad electrodes The application differs, however, in that air is used instead of felt or towelling for spacing between the electrodes and the skin Figs 168 169, and 170 illustrate the application of these electrodes

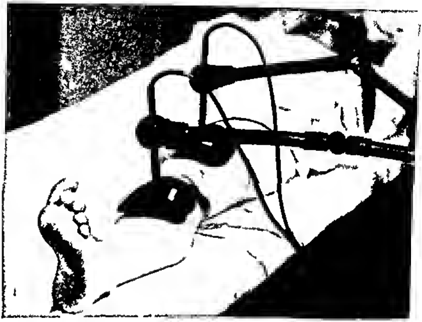


FIG 170 Flexible air spaced electrodes without spacers

Evaluation of the High Frequency Electric Field Method of Application Because the patient usually experiences a marked sensation of heat on the skin surface, it has been erroneously assumed by many that the applications described above are more effective for heating the deeper tissues of the body than those applications and technics which do not heat the skin surface excessively Experiments conducted on the thighs of living human subjects at Northwestern University Medical School have shown that, when the temperature of the skin is high, the temperature of the deeper tissues is proportionally low Conversely, it was found that the rise of temperature in the deeper tissues was progressively higher as the surface temperature decreased It was found that the induction field method of application, for example

TABLE 57

CAUSES AND ELIMINATION OF HOT SPOTS

Type of Electrode	Cause	Corrective Measure
Pad or Cuff	a Concentration of perspiration in absorbent material	Replace with dry spacing material in some cases sufficient to place dry towelling between skin and spacing material
	b Non uniform pressure of electrode on skin	Equalize Pressure
	c Non symmetrical positioning of electrodes resulting in the edges on one side being closer together than the edges on the other	Re position electrodes
Air Spaced	a Pooling of perspiration on surface of skin	Dry surface
	b Non symmetrical position of electrodes	Re position electrodes
	c Non uniform spacing between electrode and skin surface	Adapt electrode to conform to contour of skin surface, or increase air spacing so that irregularities in skin surface become negligible in comparison with average air spacing

produced less surface heating and consequently made possible the input of more energy into the tissues with resultant higher deep tissue temperature

With the electric field method of application, whether by pads, cuffs, or air spaced electrodes, the impedance may not be uniform over the entire surface covered by the electrode The non uniformity of impedance will result in a non uniform distribution of current over this surface Excessive heating will occur where the current density is excessive These areas of excessive superficial heating are designated as ***hot spots*** Such hot spots are a frequent cause of discomfort and skin burns, and care must be

nance indicator will have reached its maximum deflection. If the control is moved beyond this point, deflection of the pointer will decrease, the control being usually so designed that the decrease in deflection is relatively great for a slight increase in rotation of the control beyond the point of resonance. The dial of this indicator frequently has a milliampere scale, and many technicians erroneously believe that the meter indicates the milliamperes delivered to the patient. This reading, however, usually bears no relationship to the energy absorbed by the patient, but merely serves to indicate when resonance has been established.

Some generators are provided with a milliammeter to indicate the plate current of the tube. In addition, some generators also provide a voltmeter to indicate the filament voltage of the tube When these are provided, the filament voltage switch should be turned on first; then, when the correct voltage has been applied to the filament, the plate current switch is closed The load circuit (i e., the patient circuit) is then tuned to resonance. Some generators are provided with a voltage indicator, on the scale of which the zone of safe operation is marked.

The power input into the tissues under treatment may, if required, be increased by increasing the setting of the intensity control. After the intensity setting has been changed, the patient circuit should be retuned for resonance

Dosage. As in the case of conventional diathermy, the dosage administered is determined by the energy input per unit time, i e , the power, and the time of application The intensity, or power input per unit time, is determined by the tolerance of the tissues of the patient. This tolerance will vary with the condition of the tissues, and no hard and fast rule as to wattage input per unit volume of tissue can be given. This is a matter that the judgment of the physician, based on knowledge of the condition of the tissues to be treated, must decide. The safer procedure is to employ a lower intensity and a longer period of application As has already been pointed out, this technic of treatment presents definite advantages.

HIGH FREQUENCY INDUCTION FIELD (INDUCTOTHERMY) High frequency energy may be applied to tissue through the agency of a

high frequency magnetic field. This field is produced by means of a heavily insulated conductor, wound into a coil of appropriate configuration and number of turns, through which a high frequency current is conducted from an oscillator. The field set up about the coil induces eddy currents in the tissues in the field, such currents being most intense in the more conductive tissues

Electrodes. The coil referred to in the foregoing constitutes the electrode. The types of electrodes used for *Inductothermy,* as the heating of tissue by the induction field has been termed, are:

1. A heavily insulated, flexible conductor, wound around or about the part to be treated in the form of a helical coil

2. The same type of cable wound into a flat or pancake type of coil, which is placed over the part to be treated; or wound into two coils in such a manner that their fields are additive and placed in opposition on either side of the tissues to be treated.

3. A flexible or solid conductor wound into a permanent coil of suitable size, number of turns, and configuration and enclosed within a casing or drum of a non-conducting material to form the so-called *disk* or *drum* electrode

4. A flexible or solid conductor wound into two coils of suitable configuration and number of turns, placed within casings or drums, and so connected in series or parallel that the fields of the two coils will be additive to form the so-called *adjustable disk* or *drum electrode.* This electrode is so placed that tissues to be treated are subjected to the field obtaining between the coils This electrode facilitates the application of the induction field and provides a means of readily adapting the application to the anatomy of the part to be treated.

As already stated, the cable electrode may be applied either in the form of a helical coil wound around the part to be treated or in the form of a flat "pancake" type of coil so placed that the part to be treated will be subjected to the high frequency induction field of the pancake coil The number of turns is usually from one to three for both forms of application. In Figs 172a and 172b are shown the two types of applications using different numbers of turns Too many turns must not be employed, otherwise the coil will cease to act as an inductance and will act as a distributed

cuff, permitting current to flow from turn to turn through the superficial tissues with resultant high skin heating

Furthermore, adequate spacing between turns must be provided, otherwise leakage of current from turn to turn through the superficial tissues will take place because of the reduced capacitive

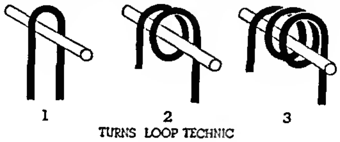


Fig 172 (a) Turns, loop technic
Fig 172 (b) Turns, pancake coil technic

reactance between the turns The spacing between the turns should be not less than 2 5 to 3 inches Most manufacturers provide spacers of insulating material to assure proper spacing of the cable. These spacers are designed to provide the proper spacing for a particular machine and cable The spacers used should be those provided by the manufacturer of the generator being employed It is also important that the cable be separated by a suitable spacer at points of crossing, otherwise excessive leakage of current will take place at these points with reduction of input into patient and excessive heating of the cable insulation at the points of crossing In the figures illustrating the technics of application the proper use of spacers is shown

Sufficient towelling or other absorbent padding should always be between the cable and the part being treated. To obtain maximum efficiency it is important that the details of the following technics be carefully observed. Towelling and other absorbent material used for spacing compresses under pressure. The thick-

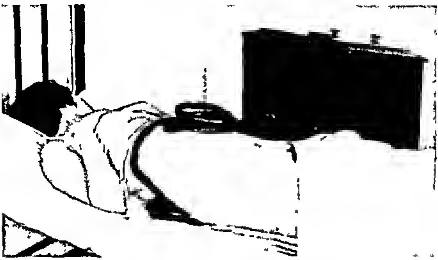


FIG 173 Double pancake coil application (From Merriman, Holmquest, and Osborne Physiotherapy Review, 14 107 1934)

ness of the padding recommended in the following technics is the thickness of the padding after the coil is positioned and treatment is to be started

As already mentioned, disk or drum applicators are also used These disk or drum applicators contain permanently wound coils of the requisite number of turns and with proper spacing between turns to assure efficient operation of the generator. When using such applicators, spacing between skin and surface of applicator is also provided by a suitable thickness of towelling or other absorbent material

A double pancake coil, of 2 to 3 turns in each coil, so wound that their fields are additive, is also used The part to be treated is placed between the two coils as shown in Fig 173.[4] The coils are

[4] Merriman, J H, Holmquest, H J; Osborne, S L Treatment Technique with the *Inductotherm*. *Physiotherapy Rev* 14 107 1934

wound in the manner illustrated in Fig 174 As the current flows through the two coils, which are wound in series, the field of the first coil is in phase with that of the second Should the two coils be wound in opposite directions, their fields would be out of phase and thus oppose each other Care must be taken when using this technic that the coils are both wound in the same direction Coils

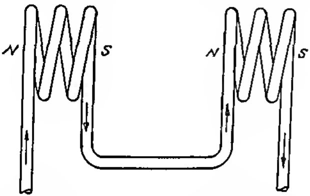


Fig 174 Schematic representation of the additive effect of two coils connected in series and so wound that the magnetic field of one is in phase with the field of the other Assuming the instantaneous current flow to be in the direction of the arrows with closed heads the polarity of the coils will be as indicated in the figure and the lines of magnetic flux which are continuous and close upon themselves will thread the two coils emerging at the north pole of the first coil spreading out into space and returning at the south pole of the second coil Obviously the coils may also be connected in parallel to obtain an additive magnetic effect Furthermore the coils may be of the flat 'pancake' type Practical application of this principle to short wave diathermy was first reported by Merriman Holmquest and Osborne (Physiotherapy Review 14 107 1934)

connected in parallel and so wound that their fields are additive could also be used

Measurements were made by Coulter and Osborne[5] of the heating produced in the female pelvis by various methods of applying high frequency fields These measurements demonstrated the effectiveness of the double coil technic In Fig 175 the initial and final

[5] Coulter J S and Osborne S L Short Wave Diathermy A Comparative Study in Pelvic Heating Arch Phys Ther 17 135 1936

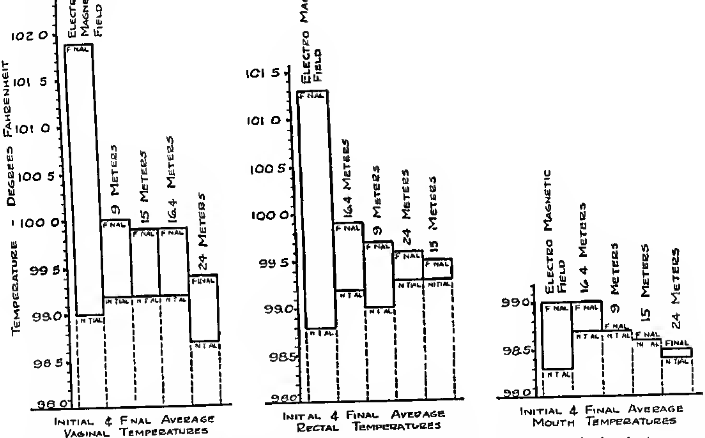


Fig 175 Initial and final vaginal and rectal temperatures obtained by induction and electric field methods of application, using double coil technic for the induction field application and various frequencies for the electric field application (From Coulter and Osborne Archives of Physical Therapy 17 135 1936)

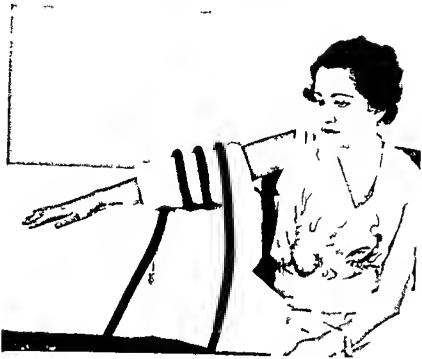


Fig 176 Elbow

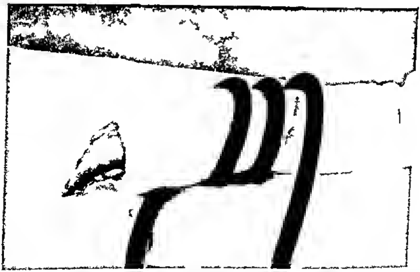


Fig. 177 Forearm

temperatures attained in the vagina and rectum by the induction field and by the electric field of various frequencies are shown. The double coil technic of applying the induction field was far superior to the electric field pad applications.

Adjustable disk or drum electrodes, utilizing the double coil

FIG. 178. Ankle.

principal of application, are available. The advantage of this type of electrode is its convenience in application to anatomical configuration, facilitating treatment of such parts, for example, as the shoulder, hip, and face. It can also be used to advantage in the treatment of other parts of the body. Towelling or other absorbent material should be used with this applicator as with other methods of applying the induction field.

Specific Technics of Application Since the clinical results are attributed to the effects of hyperemia, care must be given to the establishment and maintenance of one which is adequate Insulation of the part to be treated reduces heat loss and permits a high degree of efficiency Material used for insulation, which is applied next to the skin, should be an absorbent material such as terry-cloth or bath towelling to absorb the perspiration, and at the same

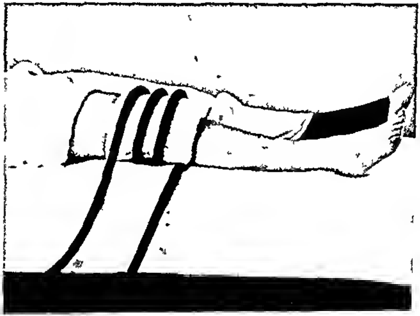


Fig 179 Knee

time supply the proper spacing for maximum efficiency Additional insulation against heat loss can be provided by covering the patient with a light blanket or sheet

Elbow, Forearm, Ankle, Knee, and Foot The method of applying the cable to these parts is shown in Figures 176, 177, 178, 179, and 180 The procedure to be followed in applying the cable and administering the treatment is as follows

1. Wrap sufficient towelling around the part so that spacing, when electrode is positioned, is at least ½ inch
2. Place three turns of the cable around the part, with the turns

separated 2½ to 3 inches. Fasten the turns in position with the cable spacers as illustrated.

3. Connect the cable terminals to the generator, keeping the leads from the coil to the generator separated by a spacer.

4. Set intensity regulator for approximately ½ output.

5. Turn on current.

6. Adjust intensity setting as patient's tolerance indicates.

It is at times desired to treat both knees, both ankles, or both

Fig 180 Foot.

feet simultaneously. Fig 181 illustrates the method of applying the cable. When using this technic it is necessary to place a folded bath towel, at least 1 inch in thickness, between the two parts being treated. The towelling for spacing is then wrapped around both parts, and application of cable is made as for the treatment of a single part

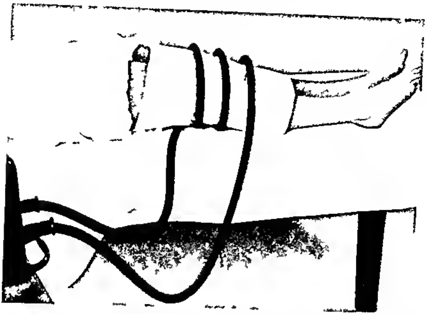


FIG 181 Both knees

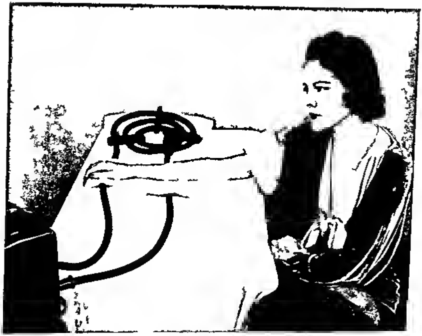


FIG 182 Hand and wrist.

Hand and Wrist

1. Form cable into a pancake coil of three turns, fixing coil position by spacing as illustrated. Fig 182.

2. Place ½ inch of bath towelling on cable as illustrated Have patient grasp towelling around far side of cable with hand to be treated, and rest forearm across towelling on near side of cable.

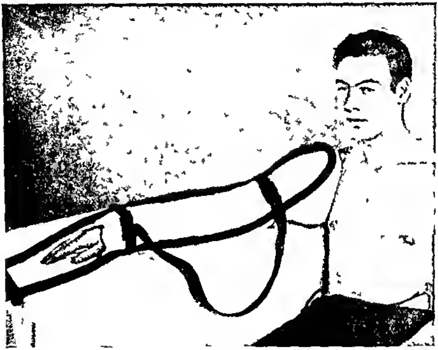


Fig 183 Upper or lower extremity (one turn)

3. Set intensity regulator for approximately ½ output
4. Turn on current.
5. Adjust intensity setting as patient's tolerance indicates

Upper or Lower Extremity (Entire)

1. Wrap ½ inch of bath towelling around extremity as shown in Fig. 183.

2. Place a single loop the full length of the extremity, and secure in position with an elastic band or a bandage.

FIG 184 Upper or lower extremity (two turns)

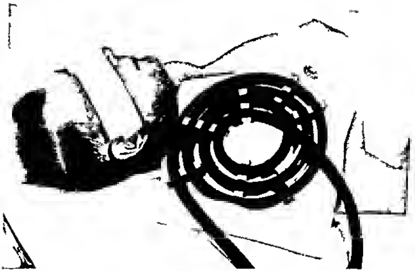


FIG 185 Shoulder

3. Connect cable to generator, keeping leads separated by a spacer.
4. Set intensity regulator for approximately ½ output
5. Turn on current.
6 Adjust intensity setting as patient's tolerance indicates.

Upper or Lower Extremity (Entire or Part)

1. Wrap ½ inch of bath towelling around extremity.
2. Place 2 turns of the cable over the extremity or part to be treated, and secure in position with spacers as illustrated Fig 184.
3 Connect cable to generator, keeping leads from coil to machine separated by a spacer
4. Set intensity regulator for approximately ½ output
5 Turn on current.
6 Adjust intensity setting as patient's tolerance indicates

Fig 186 Coil in position for ear or sinus application

Shoulder. For the purpose of illustrating the proper application of the cable, the patient is shown in a sitting position In actual treatment, the patient should be reclining but with the coil applied as illustrated in Fig 185.

1. Place ½ inch of bath towelling over the shoulder
2 Form the cable into a pancake coil of 3 turns and attach spacers Place coil on towelling in apposition with shoulder, keeping it in place with an elastic strap or sandbags
3 Connect cable terminals to generator, keeping leads separated by a spacer.
4. Set intensity regulator for approximately ½ output.

Fig 187 Ear

Fig 188 Sinus

FIG 189 Neck

5. Turn on current.
6. Adjust intensity setting as patient's tolerance indicates

Ear or Sinus

1. Form the cable into a pancake coil of 3 turns, and attach spacers as illustrated in Fig. 186.
2. Place a pillow over the coil.
3. Position the patient with the region to be treated in apposition with the coil Fig. 187 and Fig. 188.
4. Connect cable terminals to the generator, keeping the leads separated by a spacer.
5. Set the intensity regulator for approximately ½ output.
6. Turn on current.
7. Adjust intensity setting as patient's tolerance indicates

Neck

1. Place ½ inch of bath towelling over the neck
2. Form the cable into a coil of 2 turns, and attach the spacers Place the coil on the towelling Support the lead across the chest with a pillow. Fig. 189.

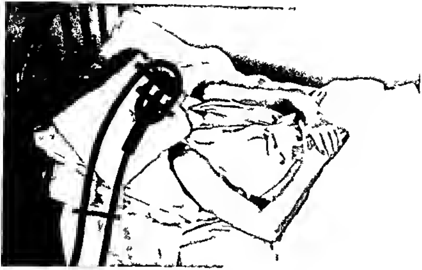


FIG 190 Eye

3 Connect cable terminals to the generator, keeping the two leads separated by a spacer
4 Set intensity regulator for approximately ½ output
5 Turn on current
6 Adjust intensity setting as patient's tolerance indicates

Eye

1 Place ½ inch of bath towelling over eye
2 Form the cable into a coil of 2 turns and attach spacers Fig 190 Place the coil on the towelling
3 Connect cable terminals to the generator, keeping the two leads separated by a spacer
4 Set intensity regulator for approximately ½ output
5 Turn on current
6 Adjust intensity setting as patient's tolerance indicates

Chest, Pelvis, and Dorsal and Lumbo sacral Spine

1 Place ½ inch of bath towelling on the surface of the area to be treated
2 Form the cable into a pancake coil of 3 turns and attach

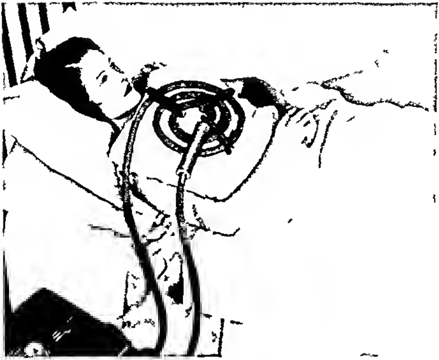


Fig 191 Chest

Fig 192 Pelvis

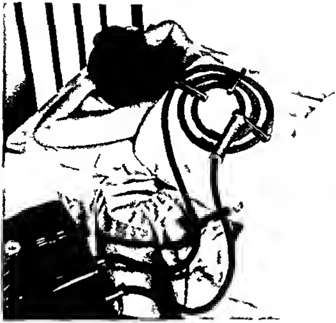


Fig 193 Dorsal spine

Fig 194 Lumbo-sacral spine

spacers Place the coil on the towelling over the area to be treated and in apposition with the part Figs 191, 192, 193, and 194

3. Connect the cable terminals to the generator, keeping the two leads separated by a spacer.

4 Set intensity regulator for approximately ½ output.

5. Turn on current.

6. Regulate intensity setting as patient's tolerance indicates

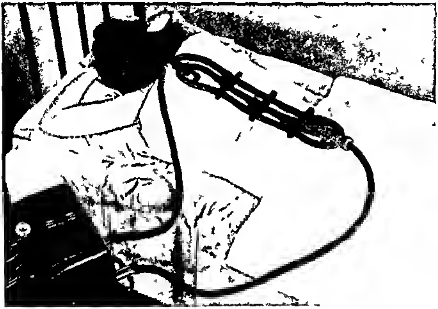


Fig 195 Entire spine

Spine (Dorsal to Sacral Region)

1. Place ½ inch of bath towelling over the back.

2. Form the cable into an elongated coil and attach spacers Place coil along spine. Fig 195.

3. Connect the cable terminals to the generator, keeping leads separated by a spacer.

4. Set intensity regulator for approximately ½ output.

5. Turn on current.

6. Regulate intensity setting as patient's tolerance indicates

Prostate

1. Cover the seat of a *wood* chair with a layer of cardboard
2. Place ½ inch of towelling or padding over the cardboard.
3. Form the cable into a pancake coil of 3 turns, attach spacers, and place on padding as illustrated. Fig. 196

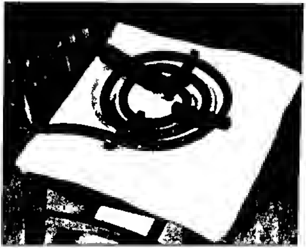


FIG 196 Coil in position for prostatic application

4 Place a pillow of such thickness over the coil that, when the patient is seated, the spacing will be 1 to 1½ inches.
5. Set intensity regulator for approximately ½ output.
6. Turn on current.
7. Regulate intensity setting as patient's tolerance indicates.

Note: Contact between thighs and scrotum should be prevented by the insertion of a hand towel to prevent arcing and excessive heating due to current concentration.

Sinus, Eye, Ear, Shoulder, Chest, Sacro iliac, Hip, and Pelvis (With the Disk Type of Electrode) Figs 197, 198, 199, 200, 201, 202, 203, and 204.

1. Place ½ inch of bath towelling over the part to be treated
2. Position the disk electrode as illustrated.
3 Connect the cable terminals to the generator, keeping the two leads separated by a spacer.

4. Set intensity regulator for approximately ½ output.
5. Turn on current.
6. Regulate intensity setting as patient's tolerance indicates

Schmitt's Optimal Dosage Technic. Believing the practice of giving treatments of twenty to thirty minutes duration, two, three,

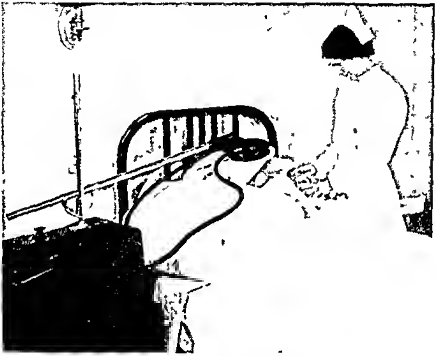


Fig 197 Sinus

or more times per week to all patients, regardless of pathology, was not rational, Schmitt introduced his *Optimal Dosage Technic.*[5] He defines optimal dosage as the smallest power input per unit tissue volume which will establish and maintain an active hyperemia, the application of which must be for such time and must be repeated for such intervals as are necessary to produce a cumulative beneficial effect. Concerning short wave diathermy, he

[5] Schmitt, M G · Optimal Dosage in Short Wave Diathermy, Arch Phys. Ther 21.716 1940

states 'The desired physiologic effect is the establishment and maintenance of an active hyperemia The technic is determined by the power input per unit tissue volume the time of application, and frequency of application"

Schmitt uses the incidence of sweating as the clinical guide for

Fig 198 Eye

judging the power input per unit tissue volume The electrodes are so applied that the adjacent, as well as the pathologic tissues are heated In addition the patient is insulated from heat loss The frequency of treatment Fig 205 may vary from one to twenty four, each 24 hour period according to whether a continuous or an intermittent hyperemia is desired Such a method of dosage would seem to have a far more scientific basis than the older and

prevalent method Schmitt's method of treatment widens the field of application and increases the effectiveness of an already valuable therapeutic agent

Evaluation of the Induction Field Method of Application There appear to be no disadvantages in the use of this method of application

Fig 199 Ear

cation On the contrary, its use presents very definite advantages Such advantages are that heat is generated primarily in the vascular tissues,[7] that the cable can be readily adapted to any part of

[7] Merriman John R Holmquest Harold J and Osborne S L A New Method of Producing Heat in Tissues The Inductotherm Am J Med Sc 187 677 1934

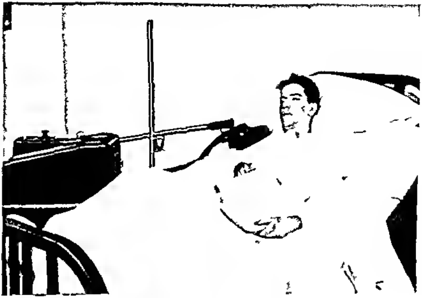


FIG 200 Shoulder

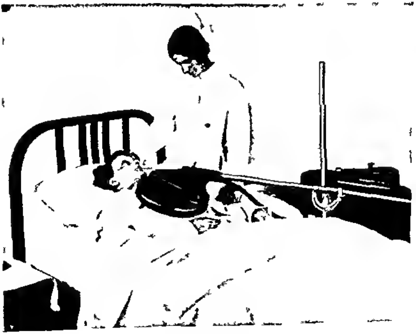


FIG 201 Chest

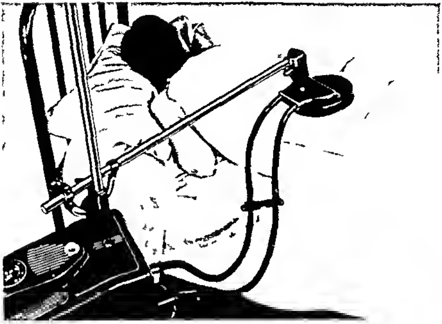


FIG 202 Sacro-iliac

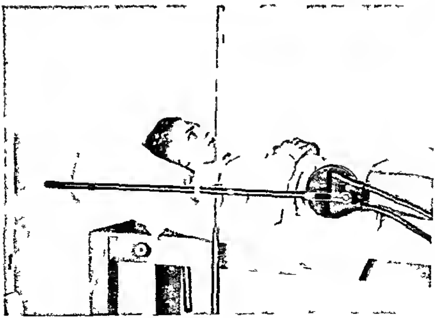


FIG 203 Hip

Fig 204 Pelvis

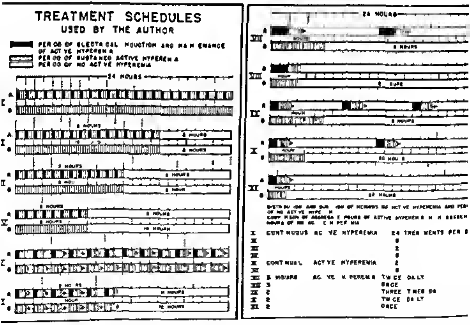


Fig 205 Treatment schedules employed by Schmitt (From Schmitt Archives of Physical Therapy 21 716 1940)

the body to be treated, and that by means of the induction cable any desired distribution of the power input can be readily achieved Furthermore, the likelihood of burns and discomfort with this method of application, when properly made, is less than with the electric field method of application.

Operation of the High Frequency Induction Generator. In contrast to the operation of the high frequency generator for applying treatment by means of the electric field, the operation of the generator for induction heating is relatively simple. The controls usually consist of an on-and-off switch, an intensity regulator, and on some units a control to tune the patient circuit into resonance with the generator.

The general procedure to be followed in operating such a machine is as follows:

1. Apply the electrode cable or the disk.
2. Connect the cable leads to the proper outlet terminals of the generator, the line switch being in the *off* position
3. Connect the line cord to a power outlet of the required voltage and frequency. If specified by the manufacturer, connect the machine to a good ground, such as a water pipe or the conduit carrying the electric circuit, if the conduit is continuous, metallic, and thoroughly grounded.
4. Set intensity control at approximately ½ of the maximum setting.
5 Turn switch to the *on* position, noting whether the unit oscillates.
6 If such control is provided, tune patient circuit into resonance.
7. Adjust the intensity control according to the patient's tolerance, or set it at some point which gives the desired input into the patient, if an input less than tolerance is to be used (Schmitt technic).

A machine may be so constructed that the cable is part of the oscillating or *tank* circuit of the generator. If there is too close coupling between the coil and the patient, the electrical constants of the circuit may become such that oscillation does not take place The remedy is obviously a looser coupling, which is achieved

by increasing the spacing between the coil and the patient, by decreasing the number of turns in the coil, or by both

If, in the case of machines which provide for tuning the patient circuit, it is impossible to tune to a condition of resonance, the cable electrode should be reapplied with fewer turns, and possibly with greater spacing between the coil and the patient

Dosage. Dosage in short wave diathermy, using either the electric or the induction field, is the total energy input It is determined by the rate of input and the time such input is applied as in the case of conventional diathermy. The intensity is that tolerated by the patient or that, as in the case of the Schmitt technic, which is arbitrarily taken as adequate for the effect desired, namely, the production and maintenance of an active hyperemia The tolerance of the patient and the judgment of the physician as to what would be adequate and yet safe are the only valid guides to intensity. The duration of treatment has been 20 to 30 minutes, repeated 2 to 4 times per week It is our opinion that longer and more frequent treatments would be conducive to better results Schmitt[9] has found such method of treatment most effective in a wide range of pathology In Fig 205 were given the duration and frequency of treatment recommended by him

V. CONTRA-INDICATIONS FOR ALL TYPES OF DIATHERMY APPLICATION. There are actually very few contra indications to the use of diathermy. However, it has been generally agreed that its employment is contra-indicated in the following conditions

1. Acute inflammatory processes accompanied by fever and non-draining suppuration, such as otitis media, appendicular abscess, and acute pelvic infections

2. A tendency to hemorrhage Diathermy should never be applied to patients having recent hemoptysis, bleeding gastric ulcers, large varicose veins, or during the period of pregnancy

3. Menstruation Diathermy should not be given through the pelvis during such period

[9] Schmitt, M G Optimal Dosage in Short Wave Diathermy Arch Phys Therap 21 716 1940

4. Areas of anesthesia.

5. Edema. Concerning edema as a contra-indication, Schmitt[9] states: "It is well to recognize that in our chief indication for diathermy, namely, inflammation, we find edema to be our *chief contra-indication*. The severity of the edema is always a definite but also a relative contra-indication."

6. Peripheral nerve lesions. In the United States it has been generally considered inadvisable to subject such lesions to treatment by high frequency because of the possibility of associated anesthesia. However, recent work by Bauwens[10] leads him to conclude:

"Provided the circulation in a paralyzed limb is capable of being accelerated, a rise in temperature and efforts to keep this near to the normal constantly are indicated, in order to promote repair, facilitate movement and increase excitability.

"This is best achieved by warming the limb in the ultra high frequency field provided by coil electrodes. Other methods are available and their efficacy is a function of their capacity to enable heat to reach deep structures without steep temperature gradients, which are hazardous in the presence of anesthesia. These provisos are not adequately satisfied with methods employing radiant heat or classical diathermy. It is not enough to warm merely the affected or cold part of a limb, as much as possible of the portion above the level should be treated so as to enhance the circulation generally. Between treatments, which should be given twice daily, every effort should be made to prevent heat losses from limbs by encasing them in sleeves or muffs made of heat-insulating materials and padded after the fashion of tea cosies."

VI. The Diathermy Prescription

A. CONVENTIONAL DIATHERMY

1. Region to be treated, e g, ...Sacro-iliac
2. Technic of application ....Transverse

[9] Schmitt, *ibid*

[10] Bauwens, P.: Heat and Electricity in the Treatment of Nerve Lesions Brit. Jour. Phys Med 5-48:1942.

3 Electrodes	Contact metal plates
4 Current intensity	Tolerance
5 Time	30 minutes
6 Frequency	Daily

B SHORT WAVE DIATHERMY

1 Region to be treated, e g,	Knee

2 Technic and application of electrodes
   a Transverse pads applied to lateral surfaces of knee
   b Double cuffs
   c Air spaced, equally spaced on anterior surface, one above and one below patella, 6 inches between centers
   d Inductance cable, encircling the knee, with 3 turns, 2½ to 3 inches apart

3 Wavelength	6, 12, 18 or 24 meters
4 Spacing	¾ to 1 inch
5 Intensity	Tolerance
6 Time	30 minutes
7 Frequency of treatment	3 times weekly

VII SURGICAL DIATHERMY In considering this most important subject, it is believed that some discussion of the nomenclature used in this field will aid in a more intelligent understanding of its principles and uses Surgery, accomplished by the use of a high frequency electric current, is commonly spoken of as *electrosurgery*, and is divided into three different classifications, which we shall speak of as *electrodesiccation*, *electrocoagulation*, and *electrocutting*

ELECTRODESICCATION (FULGURATION) Electrodesiccation may be defined as the dehydration and shrinkage of superficial tissue by damped high frequency currents Application of the current to the tissue to be destroyed is made by means of a needle-point electrode held in contact or at a slight sparking distance A relatively low intensity of current is usually employed Drying and shrinkage of the tissue treated results, due to the evaporation of the water content of the tissue cells The dry mass that remains may be curetted away or left in place to scale or slough off

Careful studies have shown that following electrodesiccation tissue cells are sbrunken aod sbriveled, with their nuclei condensed and elongated In electrodesiccatioo the tissue cells retain a suggestion of cell outline. Briefly, the result is a mummification necrosis. Since, with this type of cell destruction, there is little degenerative change and but a small amount of disintegrated material, there is only a small amount of fibrous tissue formed On this basis are the excellent cosmetic results obtained with electrodesiccation explained.

According to Kelly and Ward[17] electrodesiccation is used chiefly for lesser growths with small blood vessels, such as warts, moles, corns, and similar skin blemisbes.

ELECTROCOAGULATION. Electrocoagulation is the coagulatioo of tissue by damped high frequeocy currents Application of current is made by means of either a sharp or blunt pointed electrode, inserted into the tissue to be destroyed, with a large dispersive electrode connected to the other terminal of the high frequency generator; or by means of duotermioal active electrode, consisting of two active electrode tips or surfaces to be inserted into or applied to the tissue to be coagulated, or of a specially constructed clamp electrode with two active surfaces between wbich the tissue to be coagulated is clamped

In the case of the mono-terminal technic, coagulation takes place around the active electrode aod io diminishing degree as distance from the active electrode increases. The depth and extent of coagulation obtained varies with the strength of the current employed, the time of application, and the size or type of electrode.

In the case of the duoterminal technic, coagulation takes place between the two electrodes, both of which, since they are of the same size, are active electrodes. Obviously better control of the depth and extent of coagulation is made possible with this latter technic. To do careful and satisfactory electrocoagulation of tissue, it is of course necessary to be able to control by fine graduation the intensity of the high frequeocy current.

Following electrocoagulation, there appears, to a varying depth

[17] Kelly, Howard, and Ward, Grant Electrosurgery. W B Saunders Co, Philadelphia and London, 1932.

and extent, a change in color of the tissue to grayish-white. Histologically the cell outline is completely lost, and the coagulated tissues become fused into a structureless, homogeneous mass having an appearance not unlike that of hyalinization Briefly, the cells have been boiled by a high temperature in their own fluid. The destroyed tissue sloughs with remarkably little scar formation —much less than when the cautery is employed. By cautery is meant the application of a heated electrode to tissue for the purpose of producing destruction The destruction produced by cautery is greatest near the electrode, being chiefly superficial carbonization, which results in more extensive scar formation.

ELECTROCUTTING OR ELECTROSECTION. Electrosection may be defined as the cutting of tissue by means of an undamped or slightly damped high frequency current. The cutting current is applied by means of a needle, a knife, or a loop electrode, with a large dispersive electrode connected to the other terminal of the high frequency generator. The energized active electrode is brought into contact with the tissue to be severed and an arc is established. As the electrode is moved, the tissue separates immediately in advance of the arc, due in all likelihood to an explosion of cells from the pressure developed by the steam generated within them. Coagulation of tissue to varying depths takes place on each side of the incision. The degree of coagulation depends on the technic employed in making the incision. If too much coagulation of tissue takes place, healing of the incision will not occur by primary intention If, however, only a very thin layer of tissue on each side of the incision is destroyed, resulting in no greater quantity of necrotic cells than can be absorbed, healing will take place by primary intention.

TECHNIC OF ELECTRODESICCATION. A pointed electrode, held in a special handle, Fig 206, is connected to one of the high voltage terminals of the generator. A footswitch is connected to the generator so that the operator can control the current application to the patient by means of his foot. Current intensity is gauged by opening the spark gaps and then, while stepping on the footswitch, by holding the active needle electrode close to a coin. The spark gaps are adjusted to give a short arc if light current is required, and a

longer arc if heavy current is needed In this manner a preliminary adjustment of current is made. During actual application, however, the current intensity may need to be increased or decreased

The active electrode is approximated to the pathologic tissue and the footswitch closed The electrode does not enter the tissue,

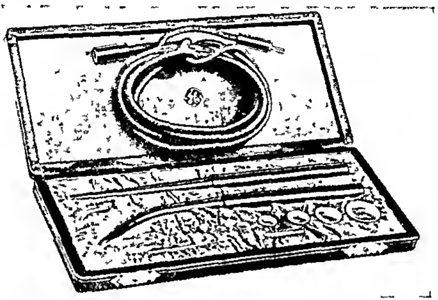


FIG 206 Electrocoagulation and desiccation electrodes

although in some cases it may make actual contact The active electrode is confined strictly to the area to be desiccated After electrodesiccation a dry mass remains, which may be curetted away or left in place to slough away Patients must be warned not to interfere with the eschar or scab which forms.

To obtain sufficient current with some machines it may be necessary to ground the second terminal of the generator to a suitable ground such as a water pipe Grounding to the chassis of the generator may suffice in some cases

TECHNIC OF ELECTROCOAGULATION. 1 *By a Single Active Electrode* Electrocoagulation differs from electrodesiccation in type and degree In electrocoagulation greater destruction, both as to

depth and area, is produced. The active electrode is introduced directly into the tissues, and connected to one terminal of the generator. The other terminal is attached to a dispersive electrode, a large metal plate, which is applied securely to some area of the body. The current employed is of high amperage and low voltage, such current as is used for direct medical diathermy application The generator is operated in the same manner as for desiccation and with a footswitch to control current flow.

It has been customary to short circuit the two diathermy terminals by means of the connecting cords, and then open the spark gaps until a given (short circuit) current is registered on the milliammeter, the given current on short circuit being that which experience has taught corresponds to the required current for the desired coagulation The active and dispersive electrodes are then connected to the diathermy terminals which were shorted, and the operation started. Further adjustment of current intensity, if necessary, can then be secured by either opening or closing the spark gaps. At the termination of the operation, the terminals can be again short circuited, and the meter read to ascertain the actual short circuit current that was used, such data enabling the operator to duplicate his technic. It must be realized that the short circuit current is not necessarily the current that flows during the application. It serves merely as a means of duplicating generator settings.

2. *By a Duo-Terminal Electrode.* A more recent development in the technic of electrocoagulation employs duoterminal electrodes, such as the *Jaros Tonsil Electrode,*[12] the *Kimble-Jaros Cervical Electrode,*[13] and the *Jaros Turbinate Electrode*[14] Figures 207, 208, and 209 The two active applicators constituting the electrode are inserted into or applied to the tissues Coagulation occurs in the zone between the two applicators By re inserting the electrodes or by moving the electrodes while maintaining contact

[12] Jaros, J F Tonsillextirpy Arch Phys Ther 17 346 1936
[13] Kimble, H E. Chronic Pyogenic Cervicitis The Medical World 56 725 1938
[14] Jaros, J F Electrocoagulation of Turbinates Arch Phys Ther 14 533·1933

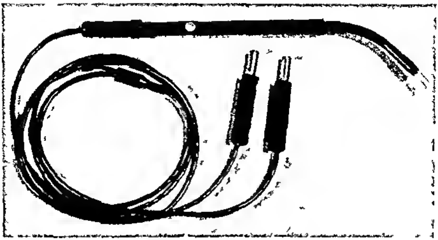


Fig 207 Jaros Tonsil electrode

with the tissues, greater areas of coagulation can be obtained With such electrodes no dispersive electrode is required

Another type of duo-terminal electrode is the so-called clamp type, such as the *Bierman Hemorrhoidal Electrode*, Fig 210 Such an electrode consists of a suitable clamp with jaws of mutually

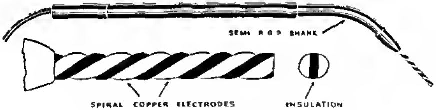


Fig 208 Kimble-Jaros Cervical Electrode

insulated metallic plates The tissue to be coagulated is clamped between these two active electrodes

TECHNIC OF ELECTROSECTION OR ELECTROCUTTING. There seems to be no general agreement on the term to be used to designate the severing of tissue by means of high frequency currents The term *Electrosurgery* includes all surgical technics with high frequency currents—desiccation, coagulation, and cutting Hence we believe that some other term should be used to designate the

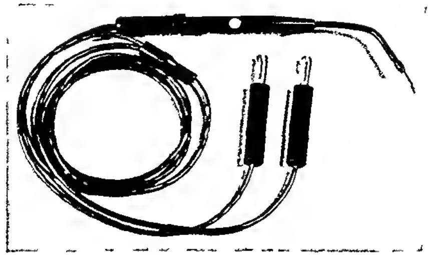


Fig 209 Jaros Turbinate Electrode

cutting of tissue—some term that would be as descriptive of this surgical procedure as electrodesiccation and electrocoagulation are for the desiccation aod the coagulation of tissue by electrical currents of high frequency Krusen suggests the term *Endosection,* as indicative of the sectiooing or cutting of tissues from within We believe, however, that the term *Electrosection* would be more

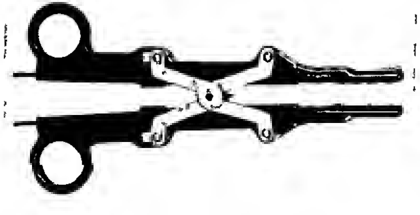


Fig 210 Bierman Hemorrhoidal Clamp Electrode.

nearly descriptive and more readily understood Furthermore, the term conforms with the terms in general use to designate the desiccation and coagulation of tissues by electricity.

The type of current employed for electrosection is a high frequency current of about 3,000,000 cycles per second. The current must be undamped, or must consist of a succession of slightly damped oscillations With the undamped current, which is obtained from a vacuum tube type of oscillator, minimal lateral coagulation is obtained for a given electrode and speed of cutting With the slightly damped current, as obtained from a spark gap type of oscillator, more coagulation is obtained If the damping of the oscillations is too great, no cutting will be obtained Such a highly damped current is used for the other surgical procedures, namely, coagulation and desiccation

The field of electrosection is extensive. No attempt will be made in this book to describe the technics to be employed, for such applications of electricity are outside the scope of this work For information on the subject it is suggested that a work such as that by Kelly and Ward[13] be consulted.

[13] Kelly, Howard, and Ward, Grant Electrosurgery W B Saunders Co, Philadelphia and London, 1932

PART D HIGH FREQUENCY CURRENTS

SECTION FOUR EFFECTS OF HIGH FREQUENCY FIELDS

The widely employed term *short wave therapy*, with qualifying wavelength to designate the therapeutic application of high frequency fields and currents of various frequencies, is unfortunate in that it connotes we are dealing with a form of radiant energy of various wavelengths capable of producing specific effects as in the case of x rays and ultraviolet and infrared radiation This is confusing and has led many to assume that, as with radiation, specific effects should be obtainable

Eidinow[1] in a discussion on short wave diathermy stated "Many workers in the field of short wave therapy have tried to establish a new physiology and a new pathology in their zeal, and have been carried away by enthusiasm Their discovery and their observations may be justly challenged, as they are incorrect and cannot be repeated by others"

In the foregoing section it was shown that the application of high frequency fields, either electric or magnetic, should and could be analyzed on the basis of electric circuit theory The effect of frequency on the absorption of power by the load and the reasons for using the range of frequencies thus far employed clinically were fully discussed

Many effects have been claimed for short wave diathermy, some well established and others which must still be considered speculative The literature on the subject contains much that deals with thermic effects In addition much discussion and experimental work has been published on types of reactions which appear without simultaneous measurable temperature rise

[1] Eidinow A Discussion on Short Wave Therapy Proc Roy Soc Med. 30 219 1937

The various effects, both those established and those for which conclusive evidence is still not available, which are claimed for short wave diathermy, will be discussed in the following paragraphs, and the evidence presented carefully evaluated in the light of present available information The importance to a physician of a knowledge of the effects of high frequency fields and of the probable mechanism by which such effects are brought about, cannot be too greatly stressed Rational therapeutic application should be based on such knowledge.

The effects claimed for short wave diathermy are thermal, electrical, bactericidal, and biologic Other effects, possibly of a chemical nature, have also been claimed The primary effects of high frequency fields are probably thermal and electrical All phenomena should, if possible, be explained in terms of generally accepted physical and chemical laws before attributing such phenomena to some assumed and mysterious effect of the causative agent. In what follows we shall attempt an explanation of the effects discussed in terms of the thermal and electrical effects of the high frequency field

After giving careful consideration to the evidence presented in the literature in support of the various effects claimed for short wave diathermy, it is our opinion that much of the disagreement is more apparent than real for the following reasons

1. That many investigators either fail to recognize the difference between heat generation in tissues and the rise in temperature, or, if they do appreciate the difference, do not make that fact sufficiently evident.

2. That, if no temperature rise can be measured, the assumption is made that no heat is being generated.

3. That laboratory experimenters only too frequently fail to maintain constant all variables except those which are to be compared

4. That clinical investigators and others who, by the conditions of the experiments, are unable to maintain all variables constant except those between which a relationship is to be determined, fail to accumulate sufficient data for statistical interpretation.

5. That, in attempting to duplicate the experiments of others, investigators have not always duplicated all conditions of the experiments with the result that data are obtained apparently disproving the point in question.

Although in our opinion, based on available evidence, all observed therapeutic effects can be explained on the basis of heat generation, with or without measurable temperature increment, we fully realize that further experimentation may present evidence substantiating claims which today are speculative However, until the proponents of such claims have presented experimental evidence which can be duplicated by others, physicians should base the application of short wave diathermy solely on effects which are at present well-established

SELECTIVE HEATING In Section Two it was shown by a mathematical and physical analysis of the heating of electrolytes in high frequency electric fields that the power absorbed, and consequently the resultant heating, is a function of the specific conductivity, the dielectic constant, and the frequency of the field The higher the frequency, the higher the concentration of the electrolyte in which energy is absorbed at the maximal rate From this fact, many erroneously concluded that, knowing the specific conductivity and the dielectric constant of the tissue to be heated, a frequency could be selected which would heat that tissue primarily without affecting materially the temperature of the contiguous tissues having different conductivities and dielectric constants but which are also subjected to the field.

There are, however, at least two very serious and insurmountable limitations to this concept, one being the effect of increased temperature on the electrical conductivity. This effect is undoubtedly considerable. In Figure 129 the resistivity of isotonic saline in ohm-cms is plotted against temperature Its resistivity at 37° C (98 6° F.) is about 52 ohm-cms and at 41° C. (105 8° F.) is 49 ohm-cms, corresponding respectively to conductivities of 0 0192 and 0 0204 ohm^{-1} cms^{-1}. Obviously, a frequency that may show selective heating at one temperature may be much less effective at higher temperatures. If the frequency f produces maximal power absorption at 37° C. when the conduc-

tivity is 0.01923 ohm^{-1} $cms.^{-1}$, a frequency of 0 0204/0 0192 f or 1.0625 f would be required to produce maximal power absorption when the temperature of the electrolyte is raised to 41° C., representing an increase in frequency of 6.25 per cent. (The dielectric constant of the electrolyte was assumed the same for both temperatures.) In Figure 138, *Curve I* gives the frequency for maximal power absorption of an electrolyte placed in an electric field for constant intensity of current as the conductivity is varied. Assuming a linear relationship, the curve can be extrapolated, obtaining for a conductivity of 0.0192 ohm^{-1} $cms.^{-1}$, a frequency of 43,200,000 cycles per second; and for a conductivity of 0 0204 ohm^{-1} $cms.^{-1}$, a frequency of approximately 6 25 per cent greater as already computed, or 45,900,000 cycles per second Hence, to maintain maximal power absorption in a given type of tissue throughout the treatment, continuous adjustment of frequency to keep pace with increasing conductivity would be required. Such procedure would be inconvenient and well-nigh impossible. Furthermore, such selective power absorption is unnecessary as will be shown later.

Secondly, as Mortimer[2] has shown, the blood flow and the rapid interchange of heat in the living body may render the differences of temperature negligible for all practical purposes, a fact which McLennan and Burton[3] also pointed out.

Schliephake's work,[4] as well as that of others on selective thermal action and uniform and penetrating heating, has been done mostly on dead tissue and on phantom models, and as Schliephake himself states: "It remains for further studies to determine the presence or absence of parallel selective reactions in the living human; hence final conclusions from the facts can be drawn only after comparison with similar observations in living human material."

Numerous measurements by various investigators on the hu-

[2] Mortimer, Bernard· Experimental Hyperthermia Induced by High Frequency Current. Radiology 16.705 1931.

[3] McLennan, J C, and Burton, A C. The Heating of Electrolytes in High Frequency Fields Canad J Research. 3·224 1930

[4] Schliephake, E · Kurzwellen Therapie Gustav Fischer, Jena, 1932

man thigh of living subjects demonstrated no specific action of different wavelengths of high frequency energy in heating the tissues of the thigh.

In a study of vaginal and rectal temperatures attained by utilizing 9, 15, 16 4, and 24-meter short wave diathermy applied to the pelvis, Coulter and Osborne[5] found no significant differences in heating effects in relation to wavelength They did find, however, a higher vaginal and rectal temperature rise, 1½ to 2° F., when the high frequency induction field was used employing a wavelength of 24 meters Fig 175. A study of their data indicates that the rise was not due to the difference in wavelength but to the method and technic of application

Horowitz, Gottesman, Derow, and Schwarzschild[6] also studied the effects of short wave diathermy on rectal and vaginal tempera tures They used nine different apparatus whose wavelength varied from 6 to 18 meters Their findings were in agreement with those of Coulter and Osborne However, when they used a localizing metal vaginal electrode in the vagina as the active electrode, they were able to secure much higher temperatures Thus the higher temperatures attained resulted, not from the wavelength used, but from the technic employed

Coulter and Carter[7] also conducted an investigation of the heating of living human tissues by short wave diathermy machines of different wavelengths Their study was undertaken to determine the efficacy of various short wave diathermy generators in heating the muscles of the thigh of living human subjects They employed electric fields of 6, 12, 18, and 24-meter wavelength, using the cuff electrode technic, and induction fields of 12, 18, and 24-meter wavelength The cuff electrode of the electric field and the coil of the induction field were selected because previous

[5] Coulter, J S, and Osborne, S L Short Wave Diathermy A Compara tive Study in Pelvic Heating Arch Phys Therapy 17 135 1935

[6] Horowitz, E, Gottesman, S, Derow, D, and Schwarzschild, M Tempera ture Elevations During Pelvic Short and Ultra Short Wave Treatment Arch Phys Therapy, X-Ray, and Radium 17 422 1936

[7] Coulter, J S, and Carter, H A Heating of Human Tissues by Short Wave Diathermy, J A M A 106 2063 1936

work by Mortimer and Osborne[8] showed these methods of application to be the most effective for heating tissues of those in general use at the time this investigation was conducted. They were unable to demonstrate that one wavelength was superior to another for heating the vascular tissues of the thigh. Coulter

TABLE 59

Author	Tissue	Maximal for Heating	Minimal for Heating
Schliephake	Fat	14 5 meters	7 meters
Gebbert	Fat	*3 to 16 meters*	*No difference*
Bachem	Fat	5 meters	Not given
Schereschewsky	Muscle	4 69 meters	
Holzer and Weissenberg	Muscle	20 meters	
Gebbert	*Muscle*	*No difference when using 3 to 16 meters*	

and Osborne[9] studied tissue heating using 6, 9, 12, 15, 18, and 24 meter wavelengths, and they too found no significant difference. They used both the induction field and the electric field Both cuffs and air-spaced electrodes were employed with the electric field. They believed that the efficiency of heating with air-spaced electrodes is dependent on the size of the electrodes, the energy available from the apparatus, the method of application, the distance of the electrodes from the skin, and the patient's tolerance.

Evidence has been presented by many workers that wavelength probably does play a part in the selective heating of non-living tissues But even in this regard the evidence presented is chaotic

[8] Mortimer, B , and Osborne, S L Tissue Heating by Short Wave Diathermy, Some Biological Observations J.A.M.A 104 1413 1935

[9] Coulter, J S , and Osborne, S L Short Wave Diathermy in Heating of Human Tissues Arch Phys Therapy 17 679 1936

and difficult of interpretation No two workers seem to agree as to the most effective wavelength for heating various non living body tissues Table 59 shows the lack of agreement in the results reported by various investigators

Fig 211 shows the results of 279 experiments made by Coulter and Osborne[10] on the thighs of adult male medical students These investigators used every type of generator then in

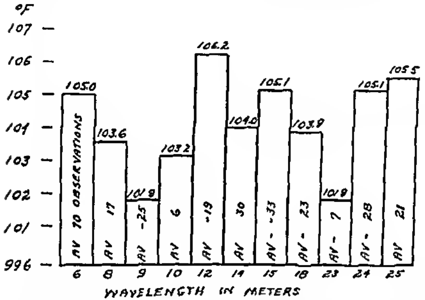


FIG 211 Average final temperatures attained at a depth of approximately 2 inches in the living human thigh at the end of a twenty minute applicat on of high frequency electric and magnetic fields of various wavelength. (From Coulter and Osborne J A M A. 110 639 1938)

use, operated under ideal conditions The wavelengths of 6 8 9 12, 14, 15, 18, 23, 24, and 25 meters were used They concluded that wavelength *per se* is not the determining factor in tissue heating in the living subject but that the characteristics of the machines, the energy delivered to the patient, and the technic of application have important roles

[10] Coulter J S and Osborne S L Wavelength in the Heating of Human Tissues by Short Wave Diathermy J A M A. 110 639 1938

Pratt and Sheard[11] concluded from their experiments on dogs subjected to an electric field having a frequency of 27 5 megacycles, corresponding to a wavelength of 10 9 meters, that when a considerable air space separates the electrodes from the surface of the tissue, the change in temperature produced in the deep-lying intra-articular tissue is greater than that produced in the subcutaneous tissues, and that the converse relation obtains when the electrodes are placed close to the surface of the tissue. They state that their experimental evidence clearly demonstrates that it is possible to produce abnormally high temperature in a chosen region by means of local applications of short wave electric energy of sufficient intensity, and, furthermore, that these relatively high temperatures may be produced in the deep tissue of the region without the simultaneous production of high temperatures in the superficial tissues of the region exposed to the high frequency electric field of the type used in their investigation.

The conclusions of Pratt and Sheard were not substantiated by the work of Coulter and Osborne, who in a series of 279 measurements of the deep and the subcutaneous temperature of the thigh of living human subjects, exposed to fields of 6 to 25 meters in wavelength, found no case in which the deep temperature exceeded that of the subcutaneous tissues for field intensities that could be tolerated by the patient However, the relative amount of heat developed in tissues exposed to high frequency fields, which differ markedly in their electrical characteristics as for example, fat and vascular tissues, can be influenced by varying wavelength and by technic of application This has already been discussed in foregoing paragraphs of this section and in Section Two on the physics of high frequency fields and currents

Rajewsky and Schafer[12] investigated the distribution of short wave energy in various body tissues to test the theory of *selective tissue heating* experimentally. They conluded there is no such

[11] Pratt, C B , and Sheard, Charles Thermal Changes Produced in Tissues by Local Applications of Radiothermy Proc. Soc Exper Biol and Med 32 766 1935

[12] Rajewsky, B , and Schafer, H · Physikalische Grundlagen der Ultra kurzwellentherapie Deutsche med Wchnschr 63 1065 1937

thing as an optimal wavelength for the selective heating of definite tissues in the body by means of the high frequency electric field

Kowarschik[13] states that the deep action of short waves depends on the size of the electrodes and their distance from the body. According to him, depth heating will be increased by increasing the size of the electrodes and by spacing them at an optimal distance from the body The coil field, he states, is superior to the condenser field as a means of producing heat in the deeper tissues These conclusions are in general agreement with the theoretical deductions in Section Two.

Krasny-Ergen[14] states that an analysis of so-called *point heating* shows that only very small differences in temperature can arise between particles of microscopic size and their surroundings He does not believe that this small difference can produce any particular effect In his opinion temperature gradients of the magnitude obtaining between microscopic particles and their suspending medium in the short wave field produce no noticeable effects Non-thermic effects he defines as those produced by forces due to electric charges which are induced in colloidal particles by the field Such effects are, according to him, the formation of chains of suspended particles, decrease of dispersity, increase of viscosity of colloidal solutions, and change of rate of sedimentation. These effects will be discussed under the heading *Specific Electric Effects*

CONCLUSIONS. From a consideration of the experimental evidence presented in the foregoing discussion, one concludes that the selective heating of an organ or of tissues, to the exclusion of other organs and tissues in the living animal, all of which are exposed to the high frequency field, is not likely to occur However, if a heterogeneous mass of tissue is exposed to a high frequency electric field, the relative proportion of the total energy input that is converted into heat in the vascular and adipose tissue components, can be controlled within limits by varying the fre-

[13] Kowarschik, J · Über die Tiefenwirkung der Kurzwellen Med Klin 33 200 1937.

[14] Krasny Ergen, W · Punktwarme und spezifische Effekts Radiologica 1·136 1937.

quency of the field Furthermore, when using the induction field, properly applied, the heat generation is primarily in the vascular *type of tissue* as *was shown by Merriman, Holmquest, and Osborne.*[15]

To this extent, and to this extent only, are we justified on the basis of available evidence to claim selective heating effects for short wave diathermy. It is to be noted that in the foregoing care was taken to use the term ***heat generation*** instead of ***temperature rise*** There may be no appreciable rise in temperature although electric energy is being absorbed, for the temperatures of the various organs and tissues quickly equalize because of the rapid transfer of heat by the circulating blood

The rapid transfer of heat by the circulating blood is the body's most fundamental mechanism for internal adjustment to external or internal thermal influences Furthermore, the circulatory changes brought about by the generation of heat in tissues, undoubtedly account for the beneficial therapeutic effects obtained with short wave diathermy, rather than a temperature rise of the tissues *per se*

NON-SPECIFIC HEATING From the foregoing discussion, one must conclude that the generation of heat in isolated organs or tissues without generating heat in contiguous organs or tissues, which are also subjected to the high frequency field, is not possible It is true that, by proper choice of frequency range and method of applying the high frequency energy, the rate of heat generation in tissues of certain electrical characteristics can be made greater than in tissues having markedly different characteristics It would seem preferable to generate the heat dominantly in the vascular tissues, permitting the circulating blood to convey heat to tissues of lower electrical conductivity in the manner that such tissues are warmed normally.

The degree to which the tissues or organs demonstrate a temperature elevation when heat is generated in them by short wave diathermy, will depend on the following factors (1) The effi-

[15] Merriman, J R, Holmquest, H J, and Osborne, S L A New Method of Producing Heat in Tissues, The Inductotherm Am J of Med Sciences *187 677 1934*

ciency of the circulating blood in dissipating the heat generated, (2) the thermal conductivity of the contiguous tissues, (3) the thermal capacity of the tissues absorbing the energy; and (4) the rate at which energy is being absorbed.

Although no appreciable rise may take place in the temperature of the energy absorbing tissues, that very fact provides evidence that definite circulatory changes must have taken place In the case of dead tissues, the transfer of heat from one type of tissue to another is dependent only on thermal conduction, and consequently temperature measurements on such tissues give no indication of what the temperature would be in similar living tissues

Osborne[14] undertook an investigation to determine whether the temperature of bone marrow in living animals can be elevated He subjected the legs of very large dogs to high frequency fields to determine whether an elevation in temperature could be obtained, and whether such elevation is greater than that of the adjacent muscle Both electric and magnetic high frequency fields were employed With both methods of application temperature elevation of the bone marrow was obtained, average final temperatures after a 20-minute application being 104 7° F for an electric field of 6 meters, 106° F. for an induction field of 12 meters, and 107 4° F for an induction field of 24 meters Corresponding average final muscle temperatures were 106 2° F, 108 0° F, and 111 4° F. The ratios of average final muscle temperature to average final bone marrow temperature were 1 0143, 1.0190, and 1 0373, respectively for the 6 meter electric field, the 12-meter induction field, and the 24-meter induction field The degree to which the elevation of the marrow temperature was due to electrical energy being converted into heat energy within the marrow itself, and to heat being conveyed to the bone marrow by conduction and circulation from the vascular tissues, was not determined Undoubtedly both were instrumental in bringing about the temperature rise. The important conclusion that can be drawn from these experiments is that bone marrow can be heated,

[14] Osborne, S L Dissertation for Master of Science Degree Northwestern University, Evanston, 1938

but that such heating does not exceed the heating of the adjacent muscle. Fig. 212 shows the temperature rise in the bone marrow and in the muscle of the leg of a dog, and also the cooling curves.

Hibbs and Osborne[17] conducted a careful investigation of the

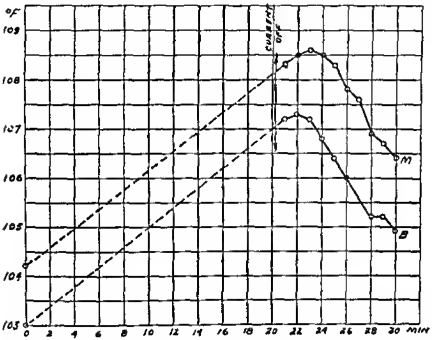


Fig 212 Temperature rise obtained in the bone marrow and muscle of the leg of a dog by application of short wave diathermy Curve M for muscle, Curve B for bone marrow

heating obtainable in the region of the prostate by various methods, including short wave diathermy by the induction field. The induction field was applied as described in the section dealing with technic. Conventional diathermy was also used, making application by means of a prostatic orificial electrode Temperatures in the posterior urethra were taken by means of a thermo-

[17] Hibbs, Donald K , and Osborne, S L Short Wave Diathermy in Chronic Prostatitis Am J. Med Sciences 201 547:1941.

couple The average rise with conventional diathermy was 5 1° F and that with the high frequency induction field 2 0° F The favorable clinical results obtained with inductothermy indicated that although the temperature attainable with that method of application is not so great as that attainable with conventional diathermy applied by means of an orificial electrode placed in the rectum in apposition to the prostate adequate heating to bring about circulatory changes which beneficially affect the pathology is achieved Heat was generated in the entire pelvis to a much greater extent by the induction field application than by conventional diathermy in which case a localizing of heat generation in the region of the prostate occurred It would seem that the more generalized heating and resultant active hyperemia obtained with inductothermy might be preferable

Andreen and Osborne [8] made measurements of the temperature of the maxillary antrum of 17 patients before and following the application of heat by various methods They found that induction heating produced the highest temperature In their patients no surgical procedures had interfered with the normal structure of the antrum Although pathologic the antrum was therefore a close approximation structurally to that of the average person Each patient had active infection subacute or chronic in one or both antrums Fluid was present in many cases They found that with induction heating the average increase in temperature was 0 6° F The temperature increase ranged from 0 3° F to 2 6° F Andreen and Osborne concluded that it might well be that the therapeutic benefits are due in part to an increased circulation leading to an active hyperemia rather than to any change in temperature They expressed the view that better therapeutic results might therefore be secured with daily treatment of relatively long duration This view conforms with that expressed by Schmitt (See *Section Three*)

Puntenny and Osborne [9] conducted an experimental study on the heating of the conjunctiva the vitreous and the orbit of dogs

[8] Andreen M A and Osborne S L Measurements of the Temperature of the Max llary Sinus after Treatment by Various Methods of Heating A Comparative Study Arch. Otolog 24 331 1936

[9] Puntenny I and Osborne S L Temperature Changes and Changes

by short wave diathermy, using a high frequency electric field of 30,000,000 cycles per second applied by means of air-spaced electrodes two inches in diameter. One electrode was placed two inches from the eye, and the other two inches from the skin at the back of the oeck. Tbe electrodes were also applied, one to each eye, with a spacing of two ioches between each electrode and the eye, the distance between electrodes being five inches The time of application of the field was twenty minutes Both heating and cooling curves for the various ocular zones mentioned were obtained. It was found that these curves bore a definite relation to the body temperature, both during heating and cooling They found it impossible to restrict heating exclusively to the eye

Microscopic studies indicated that no irreparable damage resulted to the eye for eye temperatures of 106 to 107° F. maintained for twenty minutes Photographic examination showed that the caliber of the retinal vessels in the aoesthetized dog is not altered by the application of short wave diathermy under the conditions of this experimental study.

Measurements were made by Osborne[20] of the temperatures within the stomach of a human subject before, during, and after the application of a high frequency induction field to the region of the stomach Temperature measurements were made by meaos of a thermocouple in contact with the metal end of a Refus tube, which was introduced into the stomach In Fig 213 the temperatures measured within the stomach during the course of the experiment are plotted The temperature rose when the field was applied and dropped when the field was removed, proving that the temperature of the stomach can be elevated by the application of the induction field.

Schmidt, Beazell, and Ivy,[21] in an investigation of the effect of heat on the blood and lymph flow of the intestine and the colon

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in Caliber of Retinal Blood Vessels after Short Wave Diathermy. Arch Ophthal 22:211 1939

[20] *Unpublished data*

[21] Schmidt, C. R., Beazell, J M, and Ivy, A C: Effect of Heat Applied by the Elliott Treatment and Short Wave Diathermy on Blood and Lymph Flow of Intestine and Colon *(An Experimental Study in the Dog)* Arch of Phys. Therapy, X-Ray, and Radium. 18 677.1937.

of dogs, found that increase in temperature increased the flow of blood, but did not increase the flow of lymph unless the tempera ture was elevated to a point at which tissue injury occurred These investigators used both conductive heat and the short wave in duction field in their study Conductive heat was applied directly to the intestinal lumen of the experimental animals by means of the Elliott treatment regulator, which consists of a thermostatical ly controlled water bath and electrically driven pump, which cir

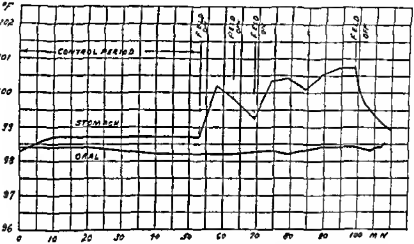

FIG 213 Effect of the high frequency induction field on the temperature of the stomach of a human subject

culates the heated water through a slightly distensible gum rubber applicator The high frequency induction field was applied by means of a coil of three turns encircling the abdomen of the ex perimental animals

In Fig 214 is plotted the blood flow in the intestine for the un treated or control group for the group in which conductive heat was employed, and for the group subjected to the induction field Immediately upon application of conductive heat directly to the intestinal lumen, the rate of blood flow began to increase whereas with the high frequeocy induction field the flow remained un altered during the first 30 minutes of application The difference in lag between application and flow iocrease for the two methods

of application seems explainable by the fact that, in the case of the conductive heat, heating of the intestine took place immediately, whereas with the induction field the temperature rise of the intestine occurred concurrently with increase in general body temperature.

During the first half hour of induction heating, the temperature of the animal was raised to 38 9° C ; during the second half hour from 38 9° to 41 5° C During the second half-hour, the blood

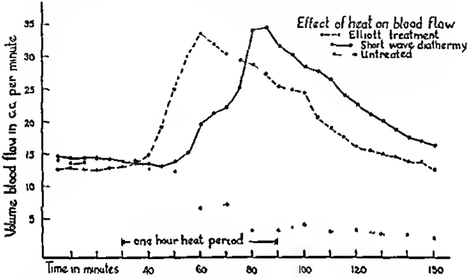

Fig 214 Effect of Heat on Intestinal Blood Flow in Dogs (From Schmidt, Beazell, and Ivy Archives of Physical Therapy, X-Ray and Radium 18 677 1937)

flow was considerably augmented The rate of blood flow rose to a maximum and then gradually diminished to the level obtaining before the experiment as it did when heat was applied locally When the flow was a maximum, approximately three times as much blood flowed through the intestinal segment. These men state that *it is of interest to note that, in artificial fever induced by the* induction field, the blood flow is increased through the visceral vessels as well as through the peripheral vessels

Specific Electric Effects By electric effects are meant those effects of an electric or magnetic field which are due to the attrac-

tive or repellent forces of the electric or magnetic field, but which effects are independent of the thermal effects of such fields Should such electric effects occur, as for example the orientation of polarized molecules in an electric field, these effects must of necessity be accompanied by the generation of some heat although of relatively negligible quantity. To orient a polarized molecule or to displace an electronic orbit requires work. This work is transformed into heat, and may or may not give rise to a measurable absorption of energy and rise in temperature. To polarize the dielectric of a condenser, and so charge the condenser, a very appreciable amount of energy is required This absorption of energy, known as the dielectric hysteresis loss, results from the work done by the electric field in producing displacement of electrons within the dielectric. This energy causes a rise in temperature of the dielectric. In this case we encounter both electric and thermal effects of the electric field In the discussion that follows, it must be kept in mind that the principle of the conservation of energy holds No change in arrangement of molecules or of aggregates of molecules, or no change in their kinetic energy, can take place without the expenditure of energy This energy is usually transformed into thermal energy, manifesting itself in a temperature rise of the absorbing body. If the rate of heat dissipation is initially equal to the rate of energy input, no rise will take place. But if not, the temperature will rise until the rate of dissipation increases to equal the rate of energy absorption Obviously, this rise in temperature may be small or large In this discussion of electric effects, we shall assume that the temperature rise is negligible—but one must not assume therefore that no heat is generated. This is a point that we have repeatedly emphasized in our discussion of the effects of short wave diathermy.

Before discussing the electric effects claimed in the literature for short wave diathermy, we shall consider the general characteristics of electric and magnetic fields, both those of constant intensity and those of an alternating character, and the effect of such fields on bodies of macroscopic size under various conditions A thorough knowledge of what happens when materials of various characteristics are placed in an electric field—knowledge that is

based on experiment and well-established laws of electricity—is of inestimable assistance in understanding what may or may not happen when exposing biologic material to high frequency fields, and provides a basis on which to judge alleged effects of such fields Furthermore, such information will aid in analyzing effects that may be observed by users of short wave diathermy. Our purpose in presenting this viewpoint is to encourage the employment of well-established physical laws and concepts in the explanation of phenomena which might be observed This discussion must of necessity be brief; those desiring a more detailed and technical treatment of the subject should consult the various references given.

Characteristics of the Electric Field. The results of early experiments in the field of electrostatics may be embodied in the following qualitative laws:

1. Like charges repel, unlike charges attract.
2. The force between two charges decreases as the distance between them is increased.

The important part played in electric phenomena by the dielectric, *i.e.* the insulating medium between charged conductors, led Faraday to postulate the existence of lines of stress in this medium having the following properties:

1. They are continuous and terminate at conductors, the positive charge on one conductor and the negative charge on the other being merely the ends of these lines.
2. The direction of the line of force at any point follows the resultant of the electric forces acting on a conductor of positive potential placed at that point.
3. Dielectric lines of force in the same direction repel and in opposite directions attract one another
4. The strength of an electric field is measured by the density of the lines of force, *i e.* the number of lines per unit area at right angles to the direction of those lines.

Clerk Maxwell showed that the forces between charges could be correctly represented by assuming the Faraday lines of force to be under a tension equal to $k\,E^2/(8\pi)$ in the direction of the lines, and a pressure $k\,E^2/(8\pi)$ normal to them, and also showed

that such a system of tensions and pressures would be in equilibrium. In the expressions for tension and pressure, k is the dielectric constant of the medium and E the intensity of the field The lines of force, because of this tension, would pull the opposite charges together, and the pressure of the lines on each other at right angles to their direction would push like charges apart The lines of force would tend to shorten until the pressure at right angles to the lines would be equal to the component of the tension in this direction. One can gain a mental picture of what occurs by imagining a rubber band stretched from one point to another over a small block of rubber. The tension in the rubber band will compress the rubber block until the rubber block exerts an opposing force equal to the component of the tension tending to compress the block.

The tensile and compressive forces of the electric lines of force provide an explanation of the motion of bodies, charged and uncharged, that are placed in an electric field Furthermore, the conception of lines of force due to Faraday and Maxwell, seems to explain effects on bodies exhibiting polarity and hence possessing electric moments.

There are, however, limitations to Maxwell's theory That the electrostatic forces on charged conductors may be represented in terms of Maxwell's tension in the direction of the electric field and pressure at right angles to it, is undoubtedly true, but directly we attempt to form an idea as to the nature of the medium in which these stresses exist, we meet with grave difficulties, as has been shown by Poincaré Maxwell's idea of a state of strain in the medium, although extremely useful in studying electrical effects, breaks down as Poincaré has shown, directly we attempt to give to the medium the properties of ordinary matter

Characteristics of the Magnetic Field The early discoveries in magnetism may be summed up in the two qualitative laws

1. Like poles repel, unlike poles attract

2. The force between two poles decreases as the distance between them is increased.

The properties of the magnetic lines of force, postulated by

Faraday to explain the phenomena occurring in the magnetic field surrounding a conductor carrying an electric current, are:

1. All magnetic lines of force are continuous and close upon themselves.

2. The direction of a magnetic line of force at any point follows the resultant of the magnetic forces acting on a north pole placed at that point.

3. Magnetic lines of force in the same direction repel and in opposite directions attract each other.

4. The strength of a magnetic field is measured by the density of the lines of force, *i e* the number of lines per unit area at right angles to the direction of the lines.

As in the case of the electric lines of force, there is tension along the lines of magnetic force and pressure normal to them In dynes the tension is given by the expression $\mu H^2/(8\pi)$, as is also the pressure, μ being the magnetic permeability of the medium and H the field intensity.

It is to be noted that the two fundamental laws of magnetism are analogous to the corresponding laws for electric charges. The properties of the postulated magnetic lines of force are similar to those of the electric lines of force, except that the lines of magnetic force are continuous and close upon themselves, whereas lines of electric force are continuous but terminate on conductors.

There are, however, certain fundamental differences between electric charges and magnetic poles First, every magnet has equal quantities of north and south magnetism It is impossible to isolate north and south poles on different bodies. If we wish to deal with a north pole alone, the best we can do is to employ a needle so long that the force exerted by the remote south pole in the vicinity of the north pole is negligible in comparison with that of the north pole.

A second difference is the absence of any such substance as a conductor of magnetism. There is no substance known in which magnetic poles move under the influence of magnetic forces with the freedom that electric charges move in a conductor when subjected to electric forces However, there are many similarities be-

tween magnetic and electric phenomena For example, an unmagnetized piece of iron, when placed near a pole of a strong magnet, becomes magnetized by induction in much the same way that a conductor is charged inductively when placed in an electric field An analogy closer still to magnetic induction is the polarization of a dielectric placed in an electric field

It is important to note that no force is exerted by an electric charge on a magnetic pole when both are at rest relative to the observer, and *vice versa*.

Polarization A device consisting of two parallel plates, separated by an insulator, is capable of storing up a charge of electricity. Such a device is called a capacitor or a condenser With air as the dielectric, a condenser of given dimensions will have a given capacitance Should the air be replaced by a solid or liquid dielectric, its capacitance will be increased, and the ratio of the new capacitance to that obtaining when air was the dielectric is known as the specific inductive capacitance, or dielectric constant, of the solid or liquid that was used as the dielectric * The increase in capacitance is due to a separation of the charges within the dielectric under the action of the applied field These charges are drawn toward the plates of opposite polarity, but the internal atomic forces prevent them from leaving the dielectric As a consequence of the displacement of charges in the dielectric towards the plates of opposite polarity, the potential of the positive plate tends to drop and that of the negative plate to rise If a constant difference of potential is maintained by an outside source, there will be an increase of the charge on each plate up to that point where there is a balance of the counterfield produced by the charges in the dielectric

The phenomena just described constitute what is known as *polarization* of the dielectric. There are several types of polarization: electronic polarization, in which the electrons within the atom

* Strictly speaking the dielectric constant of a material is the ratio of the capacitance of a condenser with that material as its dielectric to the capacitance of the condenser when its dielectric is a vacuum For all practical purposes, however, air at a pressure of 760 mm. Hg and a temperature of 0° C may be taken as the basis of comparison, its dielectric constant being 1 00059 as compared with unity for a vacuum

are displaced with respect to the positive nucleus; atomic polarization, or polarization due to the molecules being stretched, twisted, or bent by displacement of atoms within the molecules, molecular polarization, or polarization due to a permanently polarized condition of some of the molecules of a substance; and that type of polarization, more commonly observed in liquids and gases, due to an excess of charges, known as *space charge*, near the electrodes.

In solids at ordinary temperature, electronic polarization is by far the most important, and is a property of all dielectric substances The other types of polarization are often absent in solid dielectrics, and if present, occur only in relatively small degree. In liquids, however, the latter types of polarization are of importance. Since most biologic material partakes of the characteristics of a liquid, largely composed of polarized molecules, let us discuss in more detail polarization due to the orientation of molecular dipoles.

As stated above, polarization is sometimes due to the permanently polarized condition of some of the molecules of a substance. The molecules of some substances are symmetrical as regards their electrical atomic structure In others, however, a slight dissymmetry results in a slight separation of the mean positions of the total positive and the total negative charges of the molecule. Such a molecule is called a *polar molecule*, and has an *electric moment* equal to the product of the charge and the distance between the centers of gravity of the positive and negative charges. If such a molecule, which is called a *dipole*, is subjected to an electric field, the attractive and repellent forces between the charges and the field will tend to orient the molecule in the field with its axis set along a line of electric force. When a material containing polar molecules is placed in an electric field, these molecules will tend to rotate and will usually add a further polarizing action to the atomic polarization Hence, such a material will usually have a higher dielectric constant than one in which atomic polarization alone obtains.

The space charge, responsible for the fourth type of polarization, is made up of moving ions which actually constitute a current

through the dielectric. Because of the laws under which they are formed in the material, these ions may have a greater volume density near the electrodes than in the central region, thus bringing about a polarizing effect. However, polarization due to space charge is negligible in the case of the relatively high frequencies employed in short wave diathermy, and hence no detailed discussion of this aspect of polarization will be presented

Effect of an Electric Field on Uncharged and Charged Bodies. It is a general principle in dynamics that a system free to move will always tend to that configuration for which the total potential energy of the system is least Hence, an uncharged body, placed in an electric field, will tend to move so as to place itself in such position that the total energy of the entire system will be least The direction of the force exerted on the body can be determined by a simple consideration of the energy of the field In a uniform field, the energy of the entire system is the same, obviously, regardless of the position of the uncharged body In a uniform field, therefore, there would be no tendency for the body to move However, if the field is not uniform, a dielectric placed in the field will move from a point where the field intensity is low to a point where the intensity is greater, finally placing itself where the field is the most intense, for when in such position the energy stored in the field will be least. Thus, mica filings will orient themselves along lines of electric force in air much as iron filings place themselves along lines of magnetic force

When a block of dielectric moves into the space between two plates, having constant charges, the total capacitance is increased, the potential difference is correspondingly decreased, and the energy of the condenser is decreased. This decrease in energy has been expended in drawing the dielectric between the plates

If the potential difference between the plates is kept constant, the energy of the condenser is increased when the dielectric moves in, owing to the increase in capacitance and charge. But a corresponding amount of energy has been withdrawn from the source of the constant potential difference; and so work has been expended in attracting the dielectric, and the electric energy of the entire system has decreased.

Let us now consider a dielectric of lower specific inductive capacitance than that of the medium in which the field is established. In this case, the energy of the entire system will be greatest when the block of dielectric is in the position of maximum field strength. Hence, such a dielectric will tend to move from points of higher field strength to points of lower.

An understanding of the motion of uniformly charged bodies in an electric field can be readily obtained from an application of the fundamental law of electric charges, namely, that like charges repel and unlike attract. Charged bodies in a constant electric field would move or be displaced according to this law until equilibrium between displacement forces and forces opposing displacement has been attained.

In the foregoing discussion we have assumed a constant electric field. Let us now consider the effect of an alternating electric field. An uncharged dielectric body would tend to move in the alternating field in the same way that it moved in the constant electric field. Such a body would not, however, be subjected to a continuous force but to a varying force, corresponding to the variation of the electric field. The impulse (by which is meant the product of the force and the time it acts), the viscosity of the medium in which the body must move, the temperature and hence the degree of thermal agitation of the molecules and particles of the medium, the mass and the inertia of the body, and the size and shape of the body are factors which influence the motion of charged and uncharged bodies in an electric field. It is reasonable to assume that not only the intensity of the field but also the rate of its alternation and mode of variation with respect to time will exert an influence on the motion of a body placed in an alternating field. Conceivably, if the impulses are of short enough duration, no motion of the body as a whole will occur but only a periodic deformation in synchronism with the impulses acting upon the body. A complete analysis of the electrodynamic problems involved is beyond the scope of this book. Suffice it to say that all effects are dependent on the laws of mechanics and electricity. Hence, when investigating experimentally the motion of bodies in various media, careful observation and record should

be made of all factors that may conceivably affect in any manner the results of the experiment.

Molecular Dipoles. An electrically neutral molecule may be conceived as a more or less complex system comprised of electrically positive and electrically negative charges which quantitatively compensate each other. Such a quantitative compensation does not, however, of necessity entail a neutralization of the forces due respectively to the positive and negative charges In order that the forces due to the positive and negative electrification be completely neutralized, the center of gravity of the electropositive constituents of a molecule must coincide with the center of gravity of its electronegative constituents A charge near such a completely neutralized molecule would experience neither repulsion nor attraction. Should the centers of gravity of the electropositive and electronegative constituents of a molecule not coincide but be some distance apart, a charged body in close proximity to the molecule will experience attractive and repellent forces, which will be proportionate to the distance between the centers of gravity and the charge Such a molecule constitutes a typical electrical dipole, and is termed a *molecular dipole,* or briefly a *dipole.* The water molecule is an example of such a natural dipole

We must distinguish between natural dipoles and those molecules which apparently are neutral but which nevertheless may become polarized because of the influence exerted by some exterior electrical force. Such molecules are designated as *induced dipoles.* In them the external force has occasioned a displacement or shifting of the center of gravity of the positive charges with respect to that of the negative charges.

In the absence of an external field, molecular dipoles are distributed at random, owing to their thermal agitation and Brownian movement, and the net moment of the system per unit volume is zero But in the presence of an electric field, the permanent dipoles become oriented, the degree of orientation produced by a given field strength being greater at low temperatures where thermal agitation is small Debye has shown that for gases, in which the molecules are far apart, the average moment per molecule due to this orientation effect, in the direction of the field, is propor-

tional to the square of the permanent dipole moment of the molecule, and to the reciprocal of the absolute temperature.

Molecules in general are of several widely different types:

1. Very volatile, non-polar substances such as rare gases and aliphatic hydrocarbons.

2. Totally ionized salts such as sodium chloride, consisting of ions which migrate in an electric field, and exert intense electrostatic forces on their neighbors.

3. Intermediate between the two foregoing extremes is the great class of polar molecules.

A polar molecule does not give rise to ions capable of migration in a uniform electric field; but because of its polarity, as already pointed out, it does tend to orient itself in such a field.

Polar molecules also exert more powerful attractive forces on their neighbors than do non-polar molecules; correspondingly, they are less volatile and boil at higher temperature than non-polar molecules of similar size.

The great majority of organic compounds, apart from the hydrocarbons, are polar molecules So also are most inorganic molecules.

Among the compounds which ionize in water are two great classes: the strong electrolytes, which are completely ionized in water; and the weak electrolytes, which at moderate concentration are only slightly ionized. Relatively few electrolytes are in the class which is intermediate between these extremes.

Polar molecules fall into two great classes—one class having relatively low, the other extremely high, electric moments. The former includes the alcohols, amines, esters, ketones, nitriles, and the like. They are relatively volatile, and the intermolecular forces are not very intense, although far stronger than between non-polar molecules The second class of polar molecules includes aliphatic amino acids, peptides, proteins, betaines, and certain phospholipides. Typical compounds of this class are the amino acids, which are non-volatile. They are extremely insoluble in all non-polar solvents. But in water and in salt solutions they are relatively far more soluble. Even though they are electrically neutral, they display many properties which render them akin

to the totally ionized salts. When dissolved in water, they give solutions of much higher dielectric constant than that of water itself; whereas almost all ordinary polar molecules, when dissolved in water, decrease the dielectric constant. Such polar molecules are called *dipole ions*.

The quantitative index of the polarity of a molecule is its electric moment. The order of magnitude to be expected in simple molecules may be readily estimated. Consider a proton and an electron, each carrying a charge of magnitude 4.8×10^{-10} esu, separated by a distance of 1 angstrom (10^{-8}cm). The moment of such a system is the product of charge and distance, or, in this case, $4.8 \times 10^{-10} \times 10^{-8} = 4.8 \times 10^{-18}$ esu, or 4.8 Debye units. Nearly all molecules which are not dipolar ions have electric moments smaller than this. Water and the alcohols have less than two Debye units; ketones near 2.7; nitriles and organic nitro compounds between 3 and 4. But glycine, the simplest of the dipolar ions, has approximately 15 Debye units. The proteins are found to have electric moments of many hundreds, or even thousands, of Debye units.

Dielectric Constant. The dielectric constant of a material has been defined as the ratio of the capacitance of a condenser with that material as the insulating medium between the plates to the capacitance of the condenser with air as the dielectric. This definition applies in practice, however, only to the electrostatic case.

In short wave diathermy, we are concerned primarily with media which have the characteristics of solutions. Let us therefore consider briefly the molecular behavior of a solution with reference to its dielectric constant. It is evident that any salt dissociated into ions in a solution may be considered to have, to a certain extent, the characteristics of a condenser. A cation forms one plate of a condenser and an anion the other, with the solvent between the two ions acting as the dielectric. The dielectric constant will obviously depend on the properties of the solution. From this we may conclude that the dielectric constant is a function of the concentration of the solution.

Dipolar ions yield solutions of high dielectric constant. The

high dielectric constants are the direct consequence of the extraordinarily large electric moments of the dipolar ions Amino acids, peptides, proteins, and phospholipides give solutions of higher dielectric constant than can be found in any other known suhstances.

Dielectric constants of various liquids at 20° C. are given in Table 60. Non-polar liquids like benzene and hexane have very

TABLE 60

DIELECTRIC CONSTANTS AND DIPOLE MOMENTS OF CERTAIN IMPORTANT SUBSTANCES

(From Edsal, J T, in Schmidt, C L A The Chemistry of the Amino Acids and Proteins Charles C Thomas, Springfield, Ill., 1938 p 878)

Substance	Dielectric Constant at 20°	Dipole Moment $\times 10^{18}$ esu
Vacuum	1 00	—
Hexane	1 87	0
Octane	1 96	0
Benzene	2 28	0
Toluene	2 39	0
Diethyl ether	4 33	1 15
Chloroform	5 05	1 15
Acetone	21 4	2 75
Ethanol	24	1.7
Methanol	33	1 7
Water	80	1 9
Hydrocyanic acid	116	2 6
2 5 M Glycine in water	137	(15)

low values, near 2. Water and hydrocyanic acid have the highest values known for pure liquid, but an aqueous solution saturated with glycine, however, has a much higher value Other amino acids and peptides give solutions of dielectric constant far higber than this.

The dielectric constant of polarized liquids will vary with the frequency of the impressed field, becoming smaller as the frequency is increased. This relation between dielectric constant and frequency, with increasing frequency, leads to *anomalous dispersion*. This is due to the fact that the dipole can no longer follow the high frequency variations of the field. Since the dipole mole-

cule rotates in an environment possessing friction its orientation with the lines of electric force must take place against frictional and inertia forces Hence, there is an absorption of energy The value of the dielectric constant diminishes as the frequency is increased, and concurrently there is an increase in energy losses in the dielectric

According to Stokes, the frictional moment of a sphere of radius a, rotating in a fluid with the viscosity constant η (eta), is equal to $8\pi\eta\, a^3$ times the angular velocity of the sphere For such a sphere, the frictional coefficient of rotation, ζ (zeta), is $\zeta = 8\pi\eta\, a^3$ *

* *The Viscosity of Solutions* The viscosity of a liquid is a measure of its resistance to shearing force The viscosity coefficient is the force required per unit area to maintain unit difference of velocity between parallel planes in the liquid when the distance between the planes is unity Thus the tangential force, F required to maintain the relative velocity Δv between two parallel planes separated by a distance Δy in the direction normal to the plane of flow is

$$F = A\eta \frac{\Delta v}{\Delta y}$$

where A is the area of one of the planes of flow The viscosity coefficient η of the liquid is defined by this equation If Δy approaches zero the equation may be written in the differential form

$$F = A\eta \frac{dv}{dy}$$

where $\frac{dv}{dy}$ is known as the velocity gradient

The dimensions of the viscosity coefficient η are $ML^{-1}T^{-1}$ and is usually given in dyne seconds per square centimeter The unit of viscosity is one dyne second per square centimeter and is known as the *poise* The viscosity of water at 20°C is almost exactly 0 01 poise

The above equations were first derived by Newton who in his derivation made the assumption that the viscosity coefficient is independent of the velocity gradient in the flowing liquid The validity of this assumption has been verified for most pure liquids over a very wide range of velocity gradients The flow of such liquids is said to be Newtonian There are however important classes of liquids especially certain colloidal solutions for which this assumption is invalid In such cases experiments almost invariably indicate that η decreases with increasing velocity gradient

The viscosity of a liquid is increased by the introduction of large solute molecules Protein molecules are very large in comparison with the molecules of the solvent If such molecules are introduced into the solvent it is in

Holzer[22] assumed the radius of a colloidal molecule to be about 10^{-7}cm

If the coefficient of viscosity for blood at 38° C is 3 4 $\times$ 10^{-2}, the value taken by Holzer, the frictional moment for rotation of the spherical particle is 0 855 $\times$ 10^{-21}. It has already been pointed out that an *electric field tends to bring* about *an orientation of* dipoles

The *time of relaxation* is a measure of the time required for the oriented dipoles to revert to a random distribution if they were all oriented initially The relaxation time *t* is given by the following relation, due to Einstein,

variably found that the viscosity of the solution is greater than that of the *pure solvent.*

In the following tables are given the viscosity coefficients of water and of various oils at different temperatures

VISCOSITY OF WATER

(From Bingham and Jackson, Bull Bur Stds 14 75 1918)

Temp (°C)	Viscosity (Centipoises)
10	1 3077
20	1 0050
30	0 8007
40	0 6560

VISCOSITY OF VARIOUS OILS

(From *Handbook of Chemistry and Physics*, 23rd Ed., 1939)

Temp (°C)	Viscosity in Centipoises			
	Castor	Linseed	Olive	Rape
10	2420	—	138	385
20	986	—	84	163
30	451	33 1	—	96
40	231	—	36 3	—
50	—	17 6	—	—

[22] Holzer, W, and Weissenberg, E Foundation of Short Wave Therapy Hutchinson's Scientific and Technical Publications, London, 1935

$$t = \frac{\zeta}{2AT},$$ where A is Boltzmann's

constant (1.37×10^{16} ergs per degree) and T the absolute temperature The relaxation time for blood from the given data is computed by Holzer to be

$$t = \frac{0\,855 \times 10^{21}}{2 \times 1\,37 \times 10^{16} \times 311} \text{ or } 10^{-8} \text{ seconds}$$

Holzer multiplies this relaxation time by the velocity of light (300,000,000 meters per second) and obtains 3 meters as the minimum wavelength of the field that should give rise to the orientation of a dipole of 10^{7} cm radius in blood having a viscosity of 3.4×10^{2}. This wavelength corresponds to a frequency of 100,000,000 cycles per second

The limits of colloidal size as given by various authorities differ somewhat The lower limit is placed at 1 to 5 millimicrons and the upper at 100 to 500 millimicrons Colloidal particles have enormous surface areas relative to mass The following table adapted from West* gives the diameter of various particles

Particle	Diameter in mμ
Human red cell	8000
Anthrax bacillus	6000
Micrococcus	1000
Colloidal particles	1 to 100
Starch molecule	8
Cane sugar molecule	0 7

Emulsions represent dispersions of oil droplets in water or of water droplets in oil Generally the dispersed particles are larger than the upper arbitrary colloidal limit Examples of common emulsions are milk, egg yolk, mayonnaise, and petrolager

According to Hawk and Bergeim,[23] the average radius of protein molecules ranges from 2 17 to 12×10^{-7} cms If we compute the maximum frequency of the electric field that will orient dipolar molecules of this size in blood, in the same manner as

[23] Hawk, P B , and Bergeim, Olaf Practical Physiological Chemistry, 10th Edition P Blakiston's Son and Co , Inc , Philadelphia 1931

* West, E S Physical Chemistry for Students of Biochemistry and Medicine Macmillan Co , New York, 1942

Holzer computed the frequency for a colloidal particle of radius 10^{-7} cm, we obtain a frequency range of 57,800 to 980,000,000 cycles per second, the lower frequency being approximately that required to orient the molecule of 12×10^{-7} cm radius under the conditions assumed by Holzer

Muth, according to Liebesny,[24] claims to have shown that in an alternating electric field, ranging in frequency from 20,000 to 2,000,000 cycles per second, pearl chains are formed in fat emulsions Liebesny has demonstrated the same phenomenon in blood, and states that this specific effect is due to the alternating electric field and is independent of heating due to the field He states that these specific electric effects are capable of influencing the degree of dispersion of suspended particles, the speed of sedimentation, and the viscosity and the capillarity of the emulsion containing the suspended particles On the other hand, Eidinow,[25] using citrated and defibrinated blood, found no change in blood fragility or blood sedimentation rate, nor was he able to demonstrate changes of the protein colloids of blood and serum, meaning presumably their orientation.

Schliephake and Compere[26] claim to have observed a lowering of surface tension of certain colloidal solutions, including blood and serum, when placed in the high frequency electric field Improving upon the experimental procedure of these investigators, Curtis, Dickens, and Evans[27] repeated the experiments, but were unable to find any effect on the surface tension of serum

Concerning the formation of chains in materials subjected to electric fields and the possible significance of such formation from a biological and therapeutic viewpoint, Schliephake states:[28]

"Above a certain frequency the long chains can no longer fol-

[24] Liebesny, P · Athermic Short Wave Diathermy Arch Phy Therap 19 736 1938

[25] Eidinow, A. Discussion on Short Wave Therapy Proc Roy Soc Med 30 219 1937

[26] Schliephake, E, and Compere, A Spezifische Wirkungen des Ultra Kurzwellenfeldes Klin Wschr *12 1729 1933*

[27] Curtis, W E, Dickens, F, and Evans, S F The "Specific Action" of Ultra Short Wave Wireless Waves Nature 138 63 1936

[28] Schliephake, E · Short-Wave Therapy, Second English Edition The Actinic Press, London, 1938

low the rapid field changes, but lag behind On the other hand the cholin phosphoric acid group follows these movements, which change the form of the whole molecule Such changes may be followed by further results under certain circumstances in the living organism, which may lie in the region of colloidal chemical reactions I am thinking here of adsorption processes, as well as the effect of the surface tension and potential of the membranes, all of which play an important part in the life of the cell Whether and to what extent any of these processes can be influenced will depend on the molecules the wave lengths used may affect, and to what cell structures these colloids belong

"These effects can only be comprehended on biological lines, and may escape electrical and chemical methods of measurement As we know from pharmacology, extremely small changes in the smallest particles may suffice to cause profound biological effects, In the chemistry as a whole or in the electrical occurrences there are, however, no measurable changes to be found"

CONCLUSION. From the foregoing theoretical analysis, it would seem highly improbable that electric fields, of the intensity and frequency currently employed in short wave diathermy, would have any great effect in bringing about the orientation of organic polar molecules of the size obtaining in the body, in fluids having the viscosity coefficient of blood In fact, from the dynamics of the problem, it is improbable that such polar molecules would be set into appreciable oscillation by the extremely high frequencies of the order of 10,000,000 to 100,000,000 cycles per second usually employed in short wave diathermy. At most there would theoretically be a displacement of charges within the molecule, and in all likelihood only of the electrons because of the relatively great mass of the protons

As has been pointed out, it is possible that, under certain conditions, uncharged particles having a specific inductive capacitance different from that of the medium in which they are immersed, and also particles such as dipoles, may be aligned in an electric field

Such aligning is brought about by the forces exerted by the

lines of electric force, tension along the lines and pressure at right angles to them, and by the attraction of dissimilar charges. *Such factors, however, as the viscosity of the fluid, the inertia of* the particles, the strength of the field, and the frequency of alternation of the field would determine whether or not the effect would be obtained. In any experiment to determine such effect of an electric field, record of these factors must be made in order that valid comparison of results may be made with those obtained by other investigators. Further investigation must be made to ascertain whether such electric effects, which are produced with negligible heat generation, are useful therapeutically.

In our opinion all reported clinical results obtained with short wave diathermy can be explained on the basis of heat generation and the physiological effects following the generation of heat in tissues. Schliephake[29] too has come to the conclusion that if there are specific effects in the short wave field, they can be produced only by physical processes, for example, electrical stresses may under certain conditions influence the structure of molecules or of colloidal particles, but in such processes *there is always also a thermal effect.*

Specific Biologic Effects. D'Arsonval[30, 31, 32] states that the motor nerve of a nerve-muscle preparation exposed to a high frequency field exhibits a state of excitability lasting for some time. According to Pflomm,[33] when a frog's heart preparation is placed in the short wave field, the heart will beat more slowly and the excursion of each beat is lessened until finally diastole ceases en-

[29] Schliephake, E. Wirkungsweise und Indikationen der Kurzwellen. Wien med. Wchnschr. 87: 771, 1937.

[30] d'Arsonval, Arsene. Action Physiologique des Courants Alternatifs. Compt. Rend. des Seances de la Soc. de Biol. 3: 283, 1891.

[31] d'Arsonval, Arsene. Électricité et Microbes. Compt. Rend. et Mem. de la Soc. Biol. 5: 764, 1893.

[32] d'Arsonval, Arsene. Dispositifs pour la Measure des Courants Alternatifs de Toutes Frequence. Compt. Rend. et Mem. de la Soc. Biol. 3: 450, 1896.

[33] Pflomm, Erich. Experimentelle und Klinische Untersuchungen uber die Wirkung ultrakurzen elektrischer Wellen auf die Entzundung. Arch. Klin. Chir. 166: 251, 1931.

tirely. He states that when the current is switched off, the heart gradually resumes its normal activity. Audiat[34] maintained that this was a specific electric effect, because beat *per se* had the opposite effect. In contrast to d'Arsonval, Audiat maintains that the excitability of a nerve-muscle preparation diminishes in a short wave electric field.

Laubry, Tournier, Walser, and Deglaude[35] state that no effects are produced with a 20 meter wavelength, but that a 3 meter wavelength accelerates the rhythm of the isolated rabbit heart and increases the excursions Delhern and Fischgold[36] claim that they found a diminished nerve excitability comparable to that of an electrotonus produced by a direct current.

Danilewsky and Worobjew[37] found that when a minimal faradic current was applied to the nerve of a frog nerve-muscle preparation with a high frequency generator operating nearby, contractions increased in amplitude. According to them, excitability of the preparation returned to its former level when the high frequency oscillator was switched off.

Hill and Taylor[38] investigated these effects on frog hearts, cilia, and nerve-muscle preparations. They used a high frequency field of 3.4 meters wave-length. When they heated their preparations in Ringer's solution, they were able to duplicate the effects secured in the high frequency field. Furthermore, they were able to get the same effects on the isolated frog's heart muscle when they placed a hot wire near the heart.

Heinle and Phelps[39] were unable to demonstrate that the elas-

[34] Audiat, J · Action des Ondes Hertbiennes Sur l'excitabilité électrique des Nerfs; Ondes Amorties Entretenues, Courtes Rev d Actinol, et de Physiothérapie 3:227.1932.

[35] Laubry, C, Tournier, J, Walser, J, and Deglaude, L · Action des Ondes Courtes sur le Coeur Isolé Académie de Médicine 112.160 1934

[36] Delhern, L, and Fischgold, H · Les Courants de d'Arsonval Diminuent l'Excitabilité Neuromusculaire C R. Acad Sci. Paris, 199 1688 1934

[37] Danilewsky, B, and Worobjew, A Über die Fernwirkung elektrischer Hochfrequenzströme auf die Nerven. Pflug Arch ges Physiol. 236 440 1935

[38] Hill, L E, and Taylor, H J: Effect of the High Frequency Field on Some Physiological Preparations Lancet 230 311:1936

[39] Heinle, R. W, and Phelps, K. R. The effect of Short Radio Waves and Heat on the Elasticity of the Aorta Am. J. Physiol. 104 347:1933

ticity of aortic rings was affected either directly by the passage of radio waves or by such temperatures as are likely to occur in the body.

Heinle and Phelps[40] also studied the effect of short radio waves on perfused cats' hearts and found that short periods of radiothermy caused immediate elevation of temperature, accompanied by an increased rate and amplitude of ventricular beats These effects disappeared when the rise in temperature was compensated for by reducing the temperature of the perfusion fluid As early as 1929, Christie and Loomis[41] concluded that the effects produced on animals could be fully explained on the basis of the heat generated, and that there was no evidence to support the theory that certain wavelengths have a specific action on living cells.

Fabre[42] tested the excitability of nerves under the influence of short waves and found changes only with field intensities which approached those destructive to tissue He reported that chronaxie in some cases was decreased, while in others it was increased

Mogendovich[43] attempted to determine the influence of ultra high frequency currents (6 meters) on nerve conductivity and excitation foci The experiments were performed with a frog nerve-muscle preparation, and myographic records were taken In accordance with the slowly cumulative action of the field, the experiments showed that the conductivity changes not immediately but several minutes after the make of the current, whereupon the muscular contractions diminish rapidly in height and are ultimately blocked completely This block is reversible if

[40] Heinle, R W, and Phelps, K R. The Effect of Short Radio Waves on Perfused Cats' Hearts Am J Physiol 104 349 1933

[41] *Christie, R. V, and Loomis, A L The Relation of Frequency to the* Physiological Effects of Ultra high Frequency Currents J Exp Med. 49 303 1929

[42] Fabre, P H Modifications de l'excitabilité des nerfs sous l'action des ondes de haute fréquense entretenues Bull et mém Soc franc. d'elektrotherap et de Radiol 46 157 1937

[43] Mogendovich, M R. Die Wirkung eines elektrischen Hochsfrequenzfeldes auf die Funktion der Nerven *Bull de biol et de méd expér de L'URSS* 4 237 1937

only short exposures are employed A similar effect on conductivity was observed for tetanic stimulation (frequency 30 40 per second)

Dalton[44] [45] claims to have 'proved indubitably" that an effect independent of the action of heat occurs in a short wave field Careful consideration of his experimental work fails to convince us that the effect of heat generated by the field was completely eliminated He states that the oscillator used by him had an output of only 1 to 2 watts and cites that fact as evidence in support of his contention that no heating effect was present An absorption of 1 watt for 20 minutes, the time of exposure he employed, is equivalent to the introduction of 288 gram calories into the absorbing body The absorbing body was a nerve muscle preparation taken from a healthy summer frog—a body which certainly does not have a great mass and consequently its temperature would conceivably be appreciably elevated if it absorbed the total output of the oscillator Dalton records no temperature measurements Assuming an absorption of only 0 1 watt, the total gram calorie input in 20 minutes would be 28 8—a quantity of heat sufficient to raise the temperature of a body having a mass of 50 grams and a specific heat of 1 0, almost 0 6° C or more than 1° F, assuming no loss of heat from the absorbing body

The literature contains contradictory reports regarding the effect of high frequency electric fields on blood vessels Pflomm,[46] using the web of a frog's leg, reported a greater dilatation of the blood vessel than could be anticipated on the basis of the temperature rise measured He also reported that the constricting effect of adrenalin on the blood vessels could be eliminated by short waves in a surprisingly short time From these and similar experiments, Pflomm concluded that there existed a specific effect

[44] Dalton P P Low Intensity Short Waves (11 3 meters) Preliminary Observations Concerning Their Effects on Living Tissues Brit J Phys Med 11 221 1937

[45] Dalton P P Experimental Proof of the Specific Effects of Low Intensity Short Waves on Living Tissues Brit J Phys Med 12 170 1937

[46] Pflomm E Experimentelle und klinische Untersuchungen uber die Wirkung ultrakurzer elektrischer Wellen auf die Entzundung Arch f klin. Chir 166 251 1931

of short waves on blood vessels namely, that dilatation would be produced independently of the effect of any heat generated by the field

Later Cignolini and Olivieri[47] investigated the problem and reached the conclusion that there was no experimental evidence for the specific effect of short waves on blood vessels and that all observed phenomena could be attributed to the heating effect of the short wave field Lob[48] too in a later publication, stated that he was unable to confirm Pflomm's results

A careful investigation of the problem was undertaken by Weisz Pick and Tomberg[49] Concerning the behavior of blood vessels in the short wave field these investigators concluded that in their animal experiments no data were obtainable for the specific effect of short waves on blood vessels and that the heating effect alone of the short wave field was responsible for the observed effects

Wetzel and Kiesselbach[50] undertook experiments to determine what biologic effects could be produced by the high frequency electric field They placed tadpoles in a glass container directly between two electrodes of a high frequency electric field and employed wavelengths of 8 and 12 meters The water temperature rose in fifteen minutes from 15 to 28° C, and during the next five minutes to 36° C The tadpoles exposed to temperatures of 28° C were unaffected, whereas those exposed to a temperature of 36° C died either immediately or soon after the experiment Wetzel and Kiesselbach pointed out that the damage done to the tadpoles was due to heat They reduced the rate of heat generation by placing 5 mm of felt between the glass jar and the electrode thereby increasing the impedance and consequently decreasing the flow of current The temperature now rose 9 to 12 degrees C in 15 to 20 minutes No particular effects on the tadpoles were observed Next Wetzel

[47] Cignolini P and Olivieri G Radiobiolog a generalis H 4 1935

[48] Lob Alfons Die Kurzwellenbehandlung in der Chirurgie Stuttgart Enke 1936

[49] Weisz H Pick J and Tomberg V The Problem of a Specific Effect of Short Waves on Blood Vessels Arch Phys Therap 19 79 1938

[50] Wetzel G W and Kiesselbach A Versuche zur Wirkung der Kurzwellenstrahlung Deutsche med. Wochnschft 62 725 1936

and Kiesselbach completely eliminated the conductive heating effect of the water in which the tadpoles were contained by running circulating water through the glass containers The tadpoles were exposed to the electric field for one half hour, twice daily No differences were noted as compared with the control tadpoles, which were not placed in the field After fourteen days of exposure the test groups were further exposed 4 to 7 hours daily for two and one half weeks At the end of these experiments, no differences were noted between the treated and the untreated groups This showed that when the heating effect is slight or entirely eliminated, there was no effect, either deleterious or beneficial, on the experimental tadpoles These tests, according to Wetzel and Kiesselbach support the assumption that the chief cause of the biologic action of the short wave electric field is the heat that is produced by the energy exchange

In the experiments of Wetzel and Kiesselbach, the tadpoles were suspended in water which undoubtedly possessed some electrical conductivity Tap water, as all know, contains ionizable compounds to a sufficient degree to render the water quite conductive Such water would conceivably possess a conductivity and a specific inductive capacity comparable to those of the tadpoles Hence, if the tadpoles were suspended in such water, there would be no tendency for lines of electric force to concentrate appreciably on the tadpoles As a result, the amount of energy absorbed per tadpole would be the same as that which would be absorbed by the water which the tadpole displaces Since the water is kept at its initial temperature, any tendency of the temperature of the tadpole to rise would be prevented by the cooling effect of the circulating water Although energy was undoubtedly absorbed by the tadpoles, the rate of dissipation of heat was sufficiently great to prevent a temperature rise The work of these experimenters indicates that no effects are produced on the tabpoles unless there is a rise in their temperature, although energy may be absorbed, converted into heat, but conducted away before measureable temperature rise results

Had the tadpoles been suspended in a medium of zero conductivity and of considerably lower dielectric constant, or had

each tadpole been encased within a thermally insulating material, temperature increase of the tadpole would have resulted because of energy absorbed by the tadpole itself. In the first case, the temperature rise of the tadpole would be due to the high rate of energy absorption because of the concentration of lines of electric force; and in the second, due to the rate of heat dissipation being negligible in comparison to the rate of heat production, even though no concentration of lines of electric force on the tadpoles took place and the field intensity to which the tadpole was subjected was the same as that obtaining in the water medium

As an example of the heating obtainable in a thermally and electrically insulated living body suspended in a medium having negligible conductivity and relatively low dielectric constant, reference is made to the work of Yamamoto, Hosono, and Murakami[51] *on the effect of short wave fields on pupae in silk cocoons* Cocoons were placed within a high frequency electric field and the time required for killing the pupae was determined for three different wavelengths (4, 7, and 14 meters) Some 3000 experiments were made The electrical factors which influenced the effectiveness of the field in killing the pupae were the frequency, the field intensity, and the time of exposure—factors which obviously determine the energy input into the pupae With field intensity at a constant value, the time required to kill the pupae increased with increased wavelength, being least for 4 meters The order of lethal effectiveness of the wavelengths employed was 4, 7, and 14 meters, corresponding to frequencies of 75, 37 5, and 18 75 megacycles This is what would be expected from the analytical discussion of electric field heating given in Section Two Temperature measurements of the cocoon and of the surface of the pupae were made, and were found to be 40° C and 50° C, respectively. Obviously under the conditions obtaining in this experiment, specific heating can be obtained Wenk[52] experimented

[51] Yamamoto, I, Hosono, H, and Murakami, I Killing Pupae in Silk Cocoon by an Ultra Short Wave Field Tokyo University of Engineering, Department of Electrical Engineering, Tokyo

[52] Wenk, Paul Zur Frage der Punkterwärmung im hochfrequenten Wechselfeld Strahlentherapie 65 657 1939

on unicellular organisms (paramecium) and found that, in accordance with the theoretical considerations of Krasny-Ergen, the temperature of these unicellular beings investigated in the high frequency alternating field was practically the same as that of the suspending solution. Consequently he was unable to demonstrate so-called *point heating*. Wenk's results should not be interpreted as excluding the possibility of heat generation but only as indicating that under the conditions of this experiment significant grading in temperature could not be obtained.

Here, again, is an instance of the fact that investigators of point heating do not seem to appreciate (1) the difference between heat and temperature, (2) the effect the conductivity and dielectric constant of the suspending medium have upon field distribution and consequent point heating, and (3) the effect thermal conductivity has on temperature gradients It is our opinion that all too often general conclusions, tending either to substantiate or to controvert point heating, have been drawn from specific experiments which may be valid for the specific experiments but which are not applicable under all conditions.

It seems reasonable to us that point heating, i e a temperature gradient between a particle and its surroundings, can be achieved when the difference between the electrical characteristics of the particle and suspending medium are great, and conversely that such heating cannot be achieved when there is no marked difference between the electrical characteristics of the particle and those of the suspending medium. The temperature gradient is determined by the relative rate of heat production in the particle and in the suspending medium and by the rate of heat exchange between them

It is believed that certain previous experiments[53, 54, 55] showed that the therapeutic effects of short wave currents are limited to

[53] Mortimer, B, and Osborne, S L. Tissue Heating by Short Wave Diathermy: Some Biologic Observations J A M A 104 1413 1935

[54] Mortimer, B, and Beard, G Tissue Heating by Short Wave Diathermy J A M A 105 510 1935

[55] Coulter, J S, and Carter, H A Heating of Human Tissues by Short Wave Diathermy J A M A 106 2063 1936

the effects of the generated heat. This view is supported by the experimental work of Malov,[56] who investigated the death of drosophila in the electric field of short and ultra short waves (from 1.3 to 107 5 meters). Malov shows that the death of the fruit flies was due to ordinary heating effects and that there was no noticeable difference in lethal effect between short and ultra short waves.

Tomberg[57] discusses the propriety of the term *athermic* as applied to the biologic effects of short wave fields It has been claimed by some that the generally accepted effective therapeutic dosage of high frequency energy is so close to the input which has deleterious effects that the customary application of short waves can be dangerous The same minority also holds that the beneficial effects of short waves are independent of thermic effects, depending rather on innate electrospecific qualities of the material treated, and that therefore all thermal manifestations should be eliminated. It should be generally recognized, however, that thermal manifestations cannot be completely eliminated and that such effects are not dangerous unless there is sheer negligence in the application of short wave therapy Tomberg, in securing beneficial therapeusis by the use of less energy, states that while the patient experiences no sensation of warmth, to conclude that thermal effects are therefore absent is, in his opinion, untenable He states that the treatment is always thermal, and that lack of heat perception on the part of the patient may be ascribed to the fact that the thermal effects occur primarily in the deeper tissues, where thermoreceptors are absent. Tomberg believes that the term *athermic,* when applied to the chemical and physical effects of short waves, is permissible and that experimental evidence exists therefor; but that no evidence has as yet been produced to show that the biologic effect of short waves is of an athermic nature.

[56] Malov, N N Über den Warmeeffekt der kurzen und ultrakurzen elektrischen Wellen und ihre spezifische Wirkung Strahlentherap 53 326. 1935

[57] *Tomberg, Victor* Athermische Kurzwellenwirkungen und athermische Behandlung Strahlentherap 59 373 1937.

The pharmacology of short waves was investigated by Hildebrandt.[58] Heretofore only the increased thermic effect of short waves on tissues was demonstrated Assuming that chemical changes are also produced, Hildebrandt first examined the histamine content of the blood following treatment with short waves according to Schliephake's method (wavelength 3 5 meters) The experiments were performed on dogs, whose thorax was exposed to the short wave curreot for one-half to one hour. At various intervals during the following 24 hours, blood specimens were taken and the histamine content determined In some an increase of several hundred per ceot was noted immediately after treatment, followed by a return to normal in two to four hours In others the histamine values were increased, gradually reaching their peak in two hours and returning slowly to normal in the following few hours. Diathermic tests yielded virtually the same results. Judging from these findings, the increase in histamine content of the blood must be attributed to the marked thermic effect of the short wave current.

Theis[59] made a thorough experimental study of the specific effects of ultra-short waves In particular he investigated the claim of Schliephake and Compere that high frequency curreot causes a change in surface tension He stated that he used a method of application designed to eliminate completely all heat effects He measured the surface tension by the method of maximal bubble pressure, by which method even small changes can be demonstrated easily. The change of surface tension due to heating could be distinguished from a specific change by measuring its course by the temperature, first in the high frequency field and then outside the field. Various organic and inorganic compounds and solutions, as well as colloidal solutions and suspensions, were investigated He found no specific change in the surface tension,

[58] Hildebrandt, Fritz Über den Einfluss der Diathermie und des Fango auf den Histamingehalt im Blut und Gewebe Klin Wchnschr 19 270 1940

[59] Theis, M · Zur Frage der spezifischen Wirkungen der Ultrakurzwellen Thermische, athermische, und spezifische Wirkungen der Ultrakurzwellen Strahlentherap 66 494 1939

not even in serum, in which Schliephake and Compere observed the greatest effect.

The action of ultrashort waves on foams was examined closely by him because they seemed to be strongly influenced. However, it was found that all observed effects could be attributed to heating.

Hasche[60] subjected covered glass cultures of embryonic chick fibroblasts, mostly from the heart of an eight-day embryo, to an electric field of 3.5 meters for an extended period. He could not demonstrate cell growth under the influence of the electric field. Furthermore, he stated that the only effect of the field which he observed was destructive. The destructive effect could not be attributed, in his opinion, to temperature rise of the culture, since destruction occurred at a culture temperature as low as 32° C, a temperature which normally accelerates cell growth. However, it occurs to us that temperatures higher than those recorded for the culture as a whole may have developed within the cells, thus accounting for the destructive effect.

Hasche[61] also presented the results of an experimental investigation of the so-called *athermic* effects of short waves. He states certain short waves reputedly possess selectivity in avoiding heat effects and may, therefore, supposedly be applied in an athermic manner. He points out, however, that little is known of what should be understood by the term *athermic short waves*. Experiments were conducted which, according to him, refute any possible effects of athermic short waves. He found no influence on the heart rate of a frog subjected to the athermic short waves. Furthermore, he observed no effect on the growth of a *staphlococcus aureus* culture exposed to high frequency electric fields of intensities insufficient to produce a measurable temperature elevation in the culture

[60] Hasche, E Die Wirkung von Kurzwellen auf Gewebenzellen Strahlen therapie 65·664·1939

[61] Hasche, E · Über „athermische" Wirkungen der Kurzwellen („Grenzstromstärke" und „Grenzwärme" als Maszeinheit bei Arbeiten mit Kurzwellen) Munchen, med Wchnschr 85·1033 1938

Curtis, Dickens, and Evans,[62] summarizing their investigations on specificity, state.

"If such an effect exists, it should be possible for the discoverers to describe at least one clear-cut experiment which could be repeated by other workers. In the absence of such evidence we consider that the great mass of inconclusive observations which has been presented is a very insecure foundation for the rapidly growing belief in specific short wave therapy. Whilst the possible existence of specific actions of ultra short waves cannot be denied, in our opinion such effects have not as yet been adequately demonstrated. We therefore find ourselves in agreement with the conclusions of a recent report to the Council on Physical Therapy of the American Medical Association, by Mortimer and Osborne *There is no conclusive evidence from the literature, nor were we able to substantiate the claim of specific biologic action of high frequency currents (short wave diathermy) In our opinion the burden of proof still lies on those who claim any biologic action of these currents other than heat*"

Specific Bactericidal Effects In 1893 d'Arsonval and Charrin[63] subjected *B pyocyaneous* to a high frequency field and claimed the results observed were not due to the heat generated but to other effects of the field Later, Haase and Schliephake[64] reported a selective lethal action with certain wavelengths on various micro organisms in vitro at a temperature of 37° C Two years later, Liebesny, Wertheim, and Schultz[65] claimed that every bacterium had its own particular lethal wavelength They also concluded that the growth of certain organisms was accelerated by some particular wavelength About this time Mellon, Szyman-

[62] Curtis, W E, Dickens, F, and Evans, S F The 'Specific Action" of Ultra Short Wave Wireless Waves Nature 138 63 1936

[63] d'Arsonval, Arsene, and Charrin Électricité et Microbes Action des Courants Induits de Haute Frequence sur le Bacille Pyocyanique Compt Rend et Mem de la Soc. de Biol 5 467 1893

[64] Haase, W, and Schliephake, E Versuche uber den Einfluss kurzer elektrischer Wellen auf das Wachstum von Bakterien Strahlentherapie. 40 133 1931

[65] Liebesny, P, Wertheim, H and Schultz H Über Beeinflussung des Wachstums von Mikroorganismen Durch Kurzwellen bestrahlung Klin Wsch. 12 141 1933

owski, and Hicks[66] duplicated these experiments, obtaining similar results Later Hicks and Szymanowski[67] performed further experiments and explained the results on the basis of the generation of heat Furthermore, Izar and Famulari[68] demonstrated these lethal and other effects could not be produced when the temperature was not permitted to rise Again, Nagell and Berggreen[69] were unable to produce any effect on gonococci by high frequency electric fields of 4, 8, or 15 meter wavelength Groag and Tomberg[70] explained the results of Liebesny, Wertheim, and Schultz on the basis of a selective rise in temperature of the micro-organisms Hasche and Leunig[71] repeated the work of Schliephake and Haase, and failed to confirm their claims when beat effects were eliminated Moreover, Johnston[72] found no effect on bacteria when the heating effect was eliminated Lentz[73] made similar observations Eidinow[74] also was unable to demonstrate any effects on bacteria suspended in serum when heat was definitely excluded Furthermore he was unable to show any effects on bacteria placed on gauze under the skin of animals, and then subjected to the electric field Mortimer and Osborne[75] in their experiments subjected broth

[66] Mellon R. R Szymanowski W T and Hicks A An Effect of Short Electric Waves on Diphtheria Toxin Independent of the Heat Factor Science 72 174 1930

[67] Hicks R A. and Szymanowski W T Biologic Action of Ultra High Frequency Currents J Inf Dis 50 1 1932

[68] Izar G, and Famulari S Sulla Azione Biologica Delle Onde Corte, Azione su Alcuni Germi Ref Med 49 1489 1933

[69] Nagell H. and Berggreen P Über Kurzwellentherapie bei Gonorrhoe Derm Z 67 151 1933

[70] Groag P and Tomberg V Zur Biologischen Wirkung kurzer elektrischer Wellen Wien Klin Wschr 47 267 1934

[71] Hasche E. and Leunig H Zur Dosierungsfrage in der Ultrakurzwellen therapie, Einfluss von Feldstarke und Frequenz auf Staphylokokken und Streptokokken in vitro Strahlentherapie 50 351 1934

[72] Johnson M M Effect of Short Radio Waves on Biologic Activities of some Bacterial Species J Lab Clin. Med 18 806 1933

[73] Lentze F A Gibt es eine elektrische Schadigung von Bakterian und Protozoen durch Ultra Kurzwellentherap e Zbl f Bakt (Abi) 126 508 1932

[74] Eidinow A Discussion on Short Wave Diathermy Proc Roy Soc Med 28 307 1935

[75] Mortimer B and Osborne S L Tissue Heating by Short Wave Diathermy Some Biologic Observations J A MA 104 1413 1935

cultures of *staphylococci, streptococci, B. melitensis, gonococci, meningococci*, and *B typhosus* to a 6-meter electric field for twenty minutes, during which time the temperature of the culture rose to 40° C, without observing any effect on the rate of growth of the micro-organisms. They also subjected rats with experimental pneumonia *for three minutes daily to the 6-meter field* without observing any change in the fatal course of the disease.

Wertheim, however, in an article published in 1937[78] maintained that *the experiments* of *Liebesny, Wertheim*, and Schultz previously referred to, together with more recent experiments, provided evidence of the specificity of certain wavelengths, and that the observed specific effects of different wavelengths are independent of the heating effect of the high frequency fields, since these effects were obtained after careful measures were taken to exclude the action of heat. The absolute elimination of all heating effects is very difficult, and, furthermore, such effects may be present even though temperature measurements that can be experimentally made indicate that no heat is being produced For example, in the case of the well-known experiment in which an emulsion of saline in oil is placed in a high frequency field, and the minute droplets of saline heated until steam is given off from the mixture with no appreciable increase in the temperature of the oil, measurement of the oil temperature might lead some to the erroneous conclusion that the effect was independent of the action of heat. Even though water were circulated about the mixture, the phenomenon would still be observed, for the thermally insulating oil would prevent cooling of the droplets of saline. This is cited to demonstrate the difficulty of eliminating heat effect Furthermore, an effect may be due to the generation of heat even though there is no measureable increase in temperature It must be realized, too, that whenever an alternating electric field is impressed upon any substance, whether that substance be an insulator or a conductor, there is some absorption of energy, and that this energy is converted into heat. Whether or not there is an

[78] Wertheim, H Über die Beeinflussung von Lebensorganen der Mikroorganismen durch die Bestrahlung mit Kurzwellen und Ultrakurzwellen Wiener klin Wschr 50 1296.1937.

appreciable temperature rise will depend upon the ability of the absorbing body to dissipate the heat generated If changes automatically take place to increase the rate of heat dissipation, as in living tissue, to such a degree that no measureable temperature rise takes place, still these changes must be attributed to the generation of heat and not to vague specific electric effects

Ozzano and Re[77] subjected several species of pathogenic bacteria to high frequency electric fields of 4 3, and 7 36 meters As a result of their experiments, they concluded that short wave fields have no selective specific action on bacteria but act abiotically by heating the environment of the bacteria

Hasche, Leunig, and Loch[78] exposed diphtheria bacilli to high frequency fields of 15 meters, 3 5 meters, and 52 cms wavelength When distilled water was employed as diluting substance, the wavelength of 52 cms had no influence on the bacilli, but the wavelength of 3 5 meters killed the bacilli in some instances When 0 4 per cent saline solution was used, the reverse was true When cystine blood agar was employed, the wavelength of 15 and 3 5 meters had no influence on the bacilli, except elevation of the temperature of the medium.

The experiments which seemingly indicate specific bactericidal action for high frequency fields may be more rationally explained on the basis of *point heating* than on the basis of specific electric effects By *point heating* is meant the raising of the temperature of the micro-organisms above their thermal death point without a corresponding elevation in the temperature of the medium It still remains to be demonstrated, however, whether such point heating effects can be utilized for the destruction of infections in the body without producing similar effects in cells.

Effect on Tumors. In 1924 Gossett, Gutman, Lakhovsky, and Magrou[79] claimed that certain plant tumors were killed when

[77] *Ozzano, T, and Re, C* L'influenza delle onde Corte hertziane sui germi patogeni. Gior di batteriol e immunol 19 535 1937

[78] Hasche, E, Leunig, H, and Loch, P Über die Beeinflussung des Diptheriebazillus durch kurze-elektrische Wellen (15 M, 3 5 M, 52 CM) Deutsche med. Wchnschr 63 1835 1937

[79] Gossett, A, Gutman, A, Lakhovsky, G, and Magrou, J Essais de Therapeutique du Cancer Expérimental des Plantes Compt Rend Soc Biol 91 626 1924

exposed to an electric field having a wavelength of two meters Schereschewsky,[80] in 1926 and 1928, subjected experimental sarcomas of the mouse and fowl to high frequency fields of wavelength 2 2 to 36.1 meters, and concluded that wavelengths of 4 58 to 4 42 meters were most effective for these tumors Schereschewsky[81] later, reviewing his work, came to the conclusion that his former results were not due to some *specific* effect but entirely to heat Pflomm[82] stated that he considered a wavelength of 3 2 meters best for rat sarcomas Reiter[83] claimed a specific effect on rats inoculated with Jensen rat sarcoma when he exposed the animal to a field having a wavelength of 3 4 meters Ross[84] exposed fowl with Rous sarcomata to a field of 29 meters wavelength and reported there was retardation of the tumor growth Haas and Lob[85] used wavelengths of 20 and 28 meters and attributed their results to the heat generated Taylor,[86, 87] in a well-controlled study, found that when heat was eliminated there was no effect on the tumors, while in the presence of heat other wavelengths than those claimed by Reiter were just as effective Dickens, Evans, and Weil-Malherbe[88] concluded that heat alone produced the observed

[80] Schereschewsky, J W Physiological Effects of Currents of Very High Frequency Pub Health Reports 41 1939 1926

[81] Schereschewsky, J W Biological Effects of Very High Frequency Electromagnetic Radiations Radiology 20 246 1933

[82] Pflomm, E Kurzwellenbestrahlung des Rattensarkomas Munsch med Wchnschr 77 1854 1930

[83] Reiter, T Über Spezifische Wirkungen der Ultra Kurzwellen Dtsch med Wschr 59 160 1933

[84] Ross, J R Effect of Exposure of Chickens Inoculated with Rous Sarcoma to Electromagnetic Waves of High Frequency Am J Cancer 18 905 1933

[85] Haas, M, and Lob, A Die sogenannten spezifischen Effekte der Kurzwellen bei der Behandlung bosartiger Geschwulste Strahlentherapie 50 345 1934

[86] Taylor, H. J · Effect of High Frequency Field on Experimental Rat Tumors with Special Reference to So-called "Specific Effect" Brit J Radiol 8 718 1935

[87] Taylor, H. J Effects of Ultra High Frequency Currents Combined with Non lethal Doses of Radium Radiations Upon Experimental Rat Tumors Brit J Radiol 9 467 1936

[88] Dickens, F, Evans, S F, and Weil Malherbe, H. The Action of Short Radio Waves on Tissues Effects Produced in Vitro Am J Cancer 28 603 1936 30 341 1937

effects on tumors They studied the action of 3 4 and 7 2 meter wavelengths on the metabolism and growth of tumor tissue *in vitro*, providing adequate cooling to eliminate heat effects No effect on metabolism was observed after the tissue had been exposed to intense fields for as long as one to two hours Tumor tissue, after exposure to the field *in vitro*, showed no inhibition of growth when transplanted into animals The total energy applied to the tumor tissue was much greater in their *in vitro* experiments than would have been possible to apply directly to the living animal

Van Everdingen[89] investigated the effect of high frequency electric fields (1 5 to 3 m in wavelength) on malignant tumors in the mouse Exposure was from 2 to 30 hours, and intensity of field was the maximum that could be borne by the animal He was unable to affect the course of the malignancy He states that the experiment demonstrated only a thermic effect of the high frequency fields

Langendorff and Langendorff[90] subjected malignant tumors to high frequency fields of various wavelengths in combination with roentgen therapy, and observed that the average duration of life in the animals was extended from 36 1 days for the controls to 50 7 days for those in the treated group For roentgen therapy alone the extension of life was to 43 3 days In addition, these investigators stated that they failed to find evidence that certain wavelengths have a specific action They assumed that Reiter s results, although produced by an apparently athermic technic, were nevertheless due to a rise in temperature in the tumor tissue

EFFECT OF TOXINS d'Arsonval and Charrin[91, 92] claimed that high frequency currents produced an effect on diphtheria toxins which was not due to heat In 1939 Mellon, Szymanowski, and

[89] Van Everdingen A G Application of Ultra Short Waves with Special Reference to Malignant Tumors Acta Radio 18 559 1937

[90] Langendorff H and Langendorff M Untersuchungen uber die Ultra kurzwellenwirkung auf Impftumoren Straklentherapie 64 512 1939

[91] d Arsonval and Charrin Action des Diverses Modalites Electriques sur les Toxins Bacteriennes Comp Rend Soc de Biol 3 (Second series) 96 1896

[92] d Arsonval and Charrin Action de l Électricite sur les Toxins Bacteriennes Comp Rend Soc de Biol 3 (Second series) 121 1896

Hicks[93] claimed a similar result Later in 1932, Szymanowski and Hicks[94] reported a marked reduction of diphtheria antitoxin, but later in the same year they concluded the results produced were caused by the generation of heat alone However, Recknagel and Schliephake[95] announced they were able to confirm the early work of Szymanowski and Hicks, which seemed to indicate the results were due to effects of the field other than the generation of heat Bateman, Loewenthal, and Rosenberg[96] reported that they were unable to produce any effect on tetanus toxin when the heat factor was carefully eliminated

[93] Mellon R R Szymanowski W T and Hicks A An Effect of Short Electric Waves on Diptheria Toxin Independent of the Heat Factor Science 72 174 1930

[94] Szymanowski W T and Hicks R A Biologic Action of Ultra High Frequency Currents J Inf Dis 50 1 1932

[95] Recknagel L and Schliephake E Kurzwellentherapie Fischer Jena 1935

[96] Bateman J B Loewenthal H and Rosenberg H. Alleged Specific Effects of High Frequency Fields on Biological Substances Nature 140 1063 1937

PART D HIGH FREQUENCY CURRENTS

SECTION FIVE TECHNIC OF GENERAL APPLICATION (ARTIFICIAL FEVER)

I. INTRODUCTION Heat in some manner has been used therapeutically for centuries No one, however, attempted until 1884 to ascertain what effect the general application of heat might have on the general body temperature Erasmus Wilson[1] in 1860 described very accurately many of the readily observable physiological changes induced by heat, but made no notation of the changes in body temperature that must have occurred during his heat treatments Phillips[2] in 1884 published his investigations on the therapeutic effects obtained with hot baths as used at Hot Springs, Arkansas, for the treatment of various diseases He carried out several carefully devised experiments both on patients and on himself, and came to the conclusion that the curative properties were due entirely to the physiological effects produced by the skillful application of water at different degrees of temperature He noted and recorded an increase of the oral tempera-

[1] Wilson, E Thermo-therapeia The Heat Cure The Treatment of Disease by Immersion of the Body in Heated Air Brit. Med J 1860

[2] Phillips, W H. Hydrotherapy Columbus Med J 2 389 1883

ture, increased respiration and pulse rate, throbbing of the carotids, and an increased apex beat of the heart These changes, he stated, were related to the temperature and duration of the hot bath. Phillips fully appreciated the clinical significance of his observations An abstract appeared in the *Columbus Medical Journal* in the same year[3] of another highly suggestive article which had appeared in the *Journal de Medicine de Paris,* entitled *Chauffage of the Genital Organs in Venereal Disease* The abstract follows:

"Following in the line of Chauveau's experiments in weakening virus by heat, Dr. Aubert suggests that the virus deposited upon the skin or in the tissues may be modified by raising the temperature of the part to 108° or 109°F. He remarks upon the cure of paronychia sometimes obtained by immersing the finger in hot water, and suggests that we might avert by this means the consequences of snake bites, dissection wounds, or a suspicious coitus M. Aubert has made a few experiments in this direction with chancroidal pus. He exposed a part of this pus for twelve hours to a temperature of about 109° F, while the rest was preserved at the ordinary temperature. Inoculations with the warmed pus were without result, but a chancroid followed the introduction of the other. He therefore concluded that chauffage destroyed, or at least rendered innocuous, the chancroid virus The author has as yet made no experiments with the virus of syphilis or gonorrhea He suggests that the high temperature is the explanation of the subsidence of syphilitic manifestations during the course of typhoid fever or other febrile disease He further asks if the fact that chancroid is not developed in the interior of the body and never passes beyond the superficial lymphatic glands may not be explained by the destruction of the virus by the heat of the deeper tissues."

Twenty-five years later, in 1909, Hill and Flack[4] published *similar observations to those of Phillips They found* that immersion up to the neck in a hot bath, 105° to 110° F, raised the

[3] Columbus Med J 2 133 1883, 1884

[4] Hill, L, and Flack, M The Influence of Hot Baths on Pulse Frequency, Blood Pressure, Body Temperature, Breathing Volume, and Alveolar Tensions in Man J Physiol 38 57:1909

oral, axillary, and rectal temperature to 102 5° to 104 6° F in fifteen to thirty minutes They also recorded blood pressure and alveolar CO_2 tension Ten years later, in *1919*, a somewhat similar investigation was conducted by Sonntag[5] In the same year, Weichbrot and Jahnel[6] showed that rabbits infected with scrotal chancres recovered more rapidly when repeatedly placed in boxes, the air of which was heated to 105 8° F for half an hour They induced temperatures of 104° to 107 6° F They also expressed the opinion that syphilis in man might be influenced similarly, provided such temperatures could be tolerated safely Then in 1926, 1927, and 1928 followed the experiments of Schamberg and Rule[7] They found that if the rabbits were immersed daily in hot water baths, they failed to develop specific lesions when inoculated with virulent treponemas In addition, experimentally produced testicular syphilomas and secondary syphilitic ulcers disappeared These laboratory results caused Schamberg and Tseng[8] in 1928 to try the effect of heat on syphilitic human subjects They deviated in their technique from the usual custom of immersing the patient in the bath for a given period of time They correlated the immersion time and the temperature of the bath with the patient's oral temperature In general the oral temperature of a patient reached approximately 105° F in 15 to 25 minutes and returned to normal within 60 to 80 minutes Hence, the induced fever was of short duration Mehrtens and Pouppirt[9]

[5] Sonntag C F Temperature Environment and Thermal Debility Lancet 1 836 1919

[6] Weichbrot R and Jahnel F Einfluss hoher Korpertemperaturen auf Die Spirochaeten und Krankheitserscheinungen der Syphiliss im Tierexperiment Deutsch. Med Wochenschr 45 483 1919

[7] Schamberg J J and Rule A M Studies of the Therapeutic Effect of Fever in Experimental Rabbit Syphilis *Arch Derm & Syphil 14 243 1926*
Schamberg J F and Rule A M The Therapeutic Effect of Hot Baths in Experimental Primary Syphilis in Rabbits J A M A *88 1217 1927*
Schamberg J F, and Rule A M The Effect of Extremely Hot Baths in Experimental Syphilis Arch. Derm & Syphil 17 322 1928

[8] Schamberg J F and Tseng H W Experiments on the Therapeutic Value of Hot Baths with Special Reference to the Treatment of Syphilis Am. J Syph & Neurol 11 337 1927

[9] Mehrtens H. G and Pouppirt P S Hyperpyrexia Produced by Baths and Permeability of the Meninges Proc Soc Exp Biol and Med 26 287 1929

in 1929, following the hot water bath technique outlined by Rosanoff[10] in 1928, obtained safely temperatures of 106° F, which level, however, was not maintained for periods longer than one to two hours In addition to placing the technic of producing artificial fever by hot baths on a scientific basis, Mehrtens and Pouppirt made an important contribution by showing how unreliable are oral temperatures Instead of taking oral temperatures, they measured rectal temperatures by means of a suitably designed thermocouple

Investigators using the hot water bath were unable to maintain the patient's temperature for an extended period, because they apparently failed to understand the cause of the rapid fall in temperature on removing the patient from the bath A rapid fall in temperature occurs when a patient is transferred from a hot bath to a comparatively cold bed, heat being transferred from the hot patient to the cooler bed until thermal equilibrium is reached This equilibrium occurs at a temperature much lower than that of the required therapeutic plateau Merriman and Osborne[11] in 1933 were able to demonstrate that when a patient was transferred from the hot water bath to a bed preheated above the rectal temperature of the patient, the rectal temperature of the patient did not drop Figure 215 shows a typical temperature curve of 104° to 105° F, induced by the hot water bath and maintained for eight hours A rectal thermocouple was used to indicate the rectal temperature of the patient throughout the entire period The sudden acceleration of pulse rate should be noted when external heat of this nature is employed for inducing fever These authors state that this is the most dangerous application so far devised, and advise against its use

Nikola Tesla,[12] an electrical engineer, first suggested in 1891

[10] Rosanoff A J A Simple Thermotherapeutic Technic Am. J Psychiat. 7 489 1928

[11] Merriman J R and Osborne S L Methods of Producing Hyperpyrexia by Various Physical Agents Ill. Med J 64 237 1933

[12] Tesla Nikola Experiments with Alternate Currents of Very High Frequency and Their Application to Methods of Artificial Illumination Amer Inst Electrical Engineers 8 267 1891

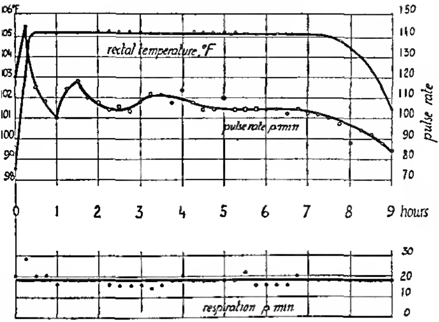

FIG 215 Hyperpyrexia by means of a hot water bath Bath temperature 110° F Patient s rectal temperature 103° F at end of 15 minutes (Note high pulse rate during induction period)

that high frequency currents might be useful in medicine In 1893 d'Arsonval[13 14 15 16] demonstrated the production of heat when high frequency current was passed through the body This led to the use of high frequency currents for the localized generation of heat and became known as diathermy In 1923 Donaggio[17] sug

[13] Arsonval Arsene d Action Physiologique des Courants Alternatifs a Grande Frequence. Arch de Physiol 5 401 1893 Paris Soc Phys Seances 72 80 1893

[14] Arsonval Arsène d L autoconduction ou Nouvelle Methode d electrisation des Êtres Vivants Mesure des Champs Magnetiques de Grande Fréquence Ac Sci C R 117 34 1893

[15] Arsonval Arsene d Proprietés Physiologiques des Courants Électriques a Haute Frequence Arch de Physiol 5 789 1893

[16] Arsonval Arsene d Influence de la Frequence sur les Effects Physiologiques des Courants Alternatifs Ac Sci C R 116 630 1893

[17] Donaggio A Discussion 6th Congress of the Italian Neurological Society Ann di Neurologia 50 386 1923

gested that the diathermy current might possibly be used for the treatment of general paresis, but nothing was done to prove or disprove his assumption In 1924 Gosset, Gutman, and Lakhovsky[18] published a report on the effect of short wave high frequency radiation on plant tumors Schereschewsky[19] reported the results of his experiments on the mouse sarcoma in 1926 Schereschewsky was probably the first to claim specific effects for such currents Later, however, in 1933, he stated that the effects he had observed should have been attributed solely to the heat generated by the absorbed electrical energy.[20, 21]

During 1925 to 1928 various biologic experiments were performed by members of the research staff of the General Electric Company under the direction of Dr W B Whitney, Director of the Research Laboratory. It was observed, according to Reynolds[22] in his review of the development of the Inductotherm, that high frequency fields, generated by a vacuum tube oscillator, could produce effects such as the killing of mice, tadpoles, and flies In 1927, according to Reynolds, it was observed that workers in proximity to a short wave radio transmitter developed a temperature rise and that Whitney, with the collaboration of Dr G Glen Smith, found that the temperatures of these men rose to 102° F., that their pulse rates increased 50 to 75 per cent, and that their blood pressure decreased some 30 to 40 per cent

In 1928, Hosmer[23] reported her work with salt solutions, tadpoles, and rats, basing her research on experimental observations made by Whitney and employing the special high frequency generator devised by him, known as the *Radiotherm* In the same

[18] Gosset, A, Gutmann, A, and Lakhovsky, G Essais de Therapeutique du Cancer Experimental des Plantes Comp rend soc biol 91 626 1924

[19] Schereschewsky, J W The Physiological Effects of Currents of Very High Frequency Public Health Rep 41 1939 1926

[20] Schereschewsky, J W Heating Effect of Very High Frequency Condenser Fields on Organic Fluids and Tissues Pub Health Rep 48 844 1933

[21] Schereschewsky, J W · Biological Effects of Very High Frequency Electromagnetic Radiation Radiology 20 246 1933

[22] Reynolds, Neil B Some Significant Steps in the Development of the Inductotherm General Electric Rev 40 171 1937

[23] Hosmer, H R Heating Effects Observed in a High Frequency Static Field Science 68 325 1928

year, Baldwin and Nelson[24] reported on the histological changes found in the various organs of rats after their rectal temperature had been raised to 45° C These workers used the condenser field in their experiments Until 1929, however, no article was published reporting the deliberate therapeutic application of high frequency currents to raise the body temperature of man In that year was published the work of Neymann and Osborne [25] These investigators used conventional diathermy, and demonstrated for the first time that it was possible to secure in man any desirable temperature, which could be maintained for any required length of time without damage to internal organs *This initiated modern artificial fever therapy*

Kahler and Knollmeyer[26] used and described an electric light cabinet as early as 1929 In 1930 Carpenter and Page[27] reported the use of the *radiotherm*, devised by Whitney, for producing fever in man This machine employed the condenser field Merriman and Osborne[28] in 1933 reported the successful use of a high frequency induction field for the production of artificial fever This generator they designated an *Inductotherm*, as being descriptive of the manner in which the device generates heat in living tissues Users of this method for producing local heating have termed the application *Inductothermy*, and for producing fever, *Inductopyrexia* Fig 216 shows the temperature, pulse, and respiration of the first patient treated by this method For insulation a *treatment bag* essentially a sleeping bag was used by Merriman and Osborne

[24] Baldwin W M and Nelson W C The Histologic Effects Produced in Albino Rats by High Frequency Currents Proc Soc Exp Biol and Med 26 588 1928

[25] Neymann C A and Osborne S L Artificial Fever Produced by High Frequency Currents Preliminary Report Illinois Med J 56 199 1929

[26] Kahler H and Knollmeyer F Über die Anwendung von kunstlicher Hyperthermie als Ersatzmittel der Experimentallen Fiebertherapie Wien Klin Wochenschr 42 1342 1929

[27] Carpenter C M and Page A B Production of Fever in Man by Short Radio Waves Science *71 450 1930*

[28] Merriman J R and Osborne S L Methods of Producing Hyperpyrexia by Various Physical Agents *Illinois Med J 64 237 1933*

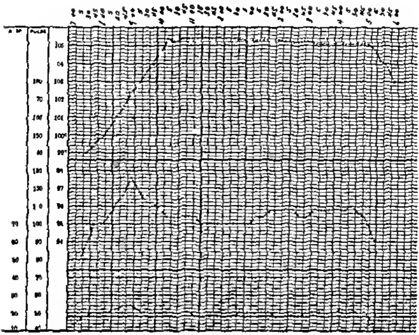

FIG 216 Temperature curve produced by electromagnetic induction (*From Merriman and Osborne Methods of Producing Hyperpyrexia by Various Physical Agents Ill Med J 64 237 1933*)

In the year 1933, Simpson, Kislig and Sittler[29] introduced the use of a cabinet in which heated and humidified air was directed over the patient for the production of fever Today the tendency is to combine such cabinets with the high frequency induction field, the induction field providing the energy to elevate the temperature of the patient to the desired plateau and the cabinet serving as a thermal insulator to minimize heat loss from the patient After the temperature is raised to the desired plateau, the cabinet alone can be used to maintain the temperature The first report of the combined use of an air conditioned cabinet and the Inductotherm for the induction and the maintenance of fever in man was that by Kimble, Holmquest, and Marshall[30] published in

[29] Simpson W M Kislig F K and Sittler E C Ultra High Frequency Pyretotherapy of Neurosyphilis Ann Int Med 7 64 1933

[30] Kimble H E Holmquest, H J and Marshall J G Electropyrexia with the Inductotherm Physiotherapy Rev 15 1 1935

1935. Previously, however, Bishop, Horton, and Warren[31] had reported in 1932 the use of a cabinet heated with incandescent lamps in combination with conventional diathermy for the administration of fever therapy Such cabinet alone has also been employed by these men for the production of fever.

II. THEORY ON WHICH ARTIFICIAL HYPERPYREXIA IS BASED. The use of fever in the therapy of certain diseases is based on the hypothesis that fever is one of the physiological defense reactions against disease

This possibility was not realized until the end of the 19th century. Prior to that time it was believed that fever was a symptom to be combatted In 1876 Rosenblum[32] purposely inoculated psychotic patients with relapsing fever with favorable results This type of fever therapy was revived in 1914 by V Wagner-Jauregg,[33] who used malaria Soon the use of other foreign substances was recommended, such as tuberculin, typhoid vaccine, and suspensions of sulphur in oil, in the treatment of general paresis. Most of the clinicians who used these forms of treatment explained their action by vague references to crossed protein immunity, increased leucocytosis, increased production of antibodies, and by the direct and spirocheticidal effect of these drugs, vaccines, and diseases Thus, the effects of non-specific protein therapy were confused with the effects of fever When a foreign substance was injected, one could not say whether the beneficial effects, if some occurred, were due to fever or to foreign protein

Investigations were undertaken to ascertain the effects of fever *per se* on various diseases and physiological processes [34] Of course it was realized that the application of heat to the skin or to the tissues may, if the temperature rises sufficiently, release autog-

[31] Bishop, F W, Horton, C B, and Warren, S L A Clinical Study of Artificial Hyperthermia Induced by High Frequency Currents Am J Med Sc *184 515 1932*

[32] Rosenblum, A Ober Otnosheney Likhoradochnikh Bolyezney k Peikhozem, Trudi Urachei Odeoskey Gorodskey Bolnitei 2 73 1876

[33] von Wagner Jauregg Die Tuberkulin Quecksilberbehandlung der Progressiven Paralyse Therap. *Monatshefte 28 1 1914*

[34] Osborne, S L Physiology of Hyperpyrexia Dissertation for the Doctorate Northwestern University, Evanston, 1940

enous protein or nitrogenous substances which may act as foreign proteins. However, it was believed that a sufficient fever, maintained for an adequate period, might do one or more of the following:

1. Kill certain organisms such as treponema pallidum
2. Increase the rate of antibody production.
3. Cause a leucocytosis.
4. Increase the blood flow through a diseased part.
5. Increase the metabolism of cells, which in turn would augment the processes concerned in resistance and repair

From the results of his investigations, Osborne[35] concludes:

"A fever can be produced in the human body of sufficient degree, and for sufficient period of time to inactivate or destroy treponema (spirocheta) pallidum in a primary lesion To what extent this is true for other organisms is uncertain and even in the case of a generalized infection with treponema, one cannot rely on fever therapy alone for the cure of the disease Although, according to the reports of some investigators, the rate of antibody production is augmented, it cannot be stated explicitly that fever augments the mobilization of antibodies from tissues to the blood stream. The mobilization of granulocytes into the blood stream should improve local defense mechanisms at least temporarily by supplying inflamed tissues with an increased source of these phagocytic cells An increase in the rate of the circulation of the blood in the body as a whole occurs in fever It is reasonable to assume that this also is true of inflamed tissues, this, however, has not been proven. An increase in metabolism of the body as a whole occurs in fever. It is reasonable to assume that this also is true of inflamed tissues, this, however, has not been proven An increase in metabolism of the body as a whole occurs in fever, but whether this improves the ability of cells to combat infection is still problematic.

"The general conception that fever facilitates the defensive mechanism of the body, is supported by the clinical results ob-

[35] Osborne, S L · Physiology of Hyperpyrexia. Dissertation for the Doctorate Northwestern University, Evanston, 1940

tained with therapeutic hyperpyrexia, particularly in early general paresis and gonorrheal arthritis The results in other diseases, such as rheumatic fever, chronic arthritis, chorea, asthma, multiple sclerosis are not so striking, with the possible exception of chorea. Fever places a strain on the cardiovascular-respiratory system, and the thermotactic system The evidence shows that these systems are subjected to less strain by employing the method of *internal heating*, than by employing the method of *external heating*. In either case, if adequate attention is devoted to the prevention of hemoconcentration and of excessive stimulation of the cardio-vascular, respiratory, and thermotactic system, the potential hazards of hyperpyrexia are obviated."

III. Technic of Application As already pointed out, many methods have been utilized for the production of artificial fever in man. It would obviously be impossible to describe the technic of all of them. Broadly speaking, all of the technics for the production of artificial fever by physical agents can be classified into two methods.

One method uses external heat, which can be applied by electric blankets, cabinets using hot air, hot water vapor, conditioned air, or radiant energy from infra-red generators or incandescent lamps The production of the fever is dependent upon the patient being in a heated environment. The deeper tissues of the body are heated by conduction from the heated superficial tissues.

The other method uses high-frequency electric currents or fields to generate heat in the tissues themselves, independently of any external application of heat, for the purpose of producing fever

In both cases it is necessary to retard the loss of heat from the body as effectively as possible to prevent the loss of too much time in reaching the desired temperature level, and to help maintain the patient's temperature at a given level with as slight fluctuation as possible.

We have used every method advocated up to the present time in an endeavor to find the best one available Our experience has led us to the conclusion that the so-called internal heating method of producing artificial fever, that is, the method employing high-

frequency electrical energy, has a much wider margin of safety than external heating methods, aod is far more comfortable to the patient. These observatioos were largely empiric in oature at first, but gradually physiological investigations are tending to substantiate our clinical observations This discussion, therefore, shall be limited to describing in detail the techoic of producing fever by high frequency currents and fields

High frequency electrical energy may be applied in one of three ways for the production of artificial fever, by means of conventional diathermy; by means of the high frequency electrical field; or by means of electromagnetic induction Each represents a successive stage of advancement

With conventional diathermy, metal electrodes, fenestrated and with a sinuated periphery, are employed They are held io position by a suitable binder. Heating of the body occurs as a result of the tissue resistance to the passage of the electric current. With the trunk sandwiched between the two electrodes, all of the current enters through the external skin and subcutaneous tissues, and then is offered various pathwoys to traverse before it agaio leaves the skin surface to complete the circuit back to the machine

This explains why for the relatively low frequencies used in conventional diathermy, subcutaneous fat in adipose patieats will heat to the point of liquefactioo, frequently leaving nodules of fat beneath the skin in the region of the electrodes, while the skin remains undamaged Unless ooe is well skilled in applying the electrodes, electrical burns also are quite liable to occur. To overcome some of these difficulties, metal cuffs on a rubber backing were used, one around each lower leg, one arouod each thigh, and another around the lower part of the abdomen This simplified the technic of application, but because the current flow in this instance is in series with some of the largest blood vessels of the body, there is a tendency to produce a marked splanchnic vasodilation with danger of vascular collapse Therefore, if conventional diathermy is used, it is best to employ the so called through and through application

Short wave generators became possible with the development of the oscillator tube, and today tissue heating by high frequency

current is accomplished almost exclusively by the so-called short wave diathermy apparatus. The currents generated by such oscillators range in frequency from 10,000,000 to 100,000,000 cycles per second, corresponding to wavelengths of 30 to 3 meters

There are two methods for using short wave medical diathermy: (1) The high frequency electric field, which uses either condenser pad electrodes, similar to the electrodes of conventional diathermy, cuff electrodes, or air-spaced electrodes; (2) The induction field, the electrode of which is a conducting cable applied around or on the body in various forms

The condenser field, while successfully raising body temperature, may produce superficial burns on the skin surface, because of the leakage of current over the skin surface when the patient begins to perspire. This disadvantage has not been overcome when employing this particular field, and is one of its decided disadvantages. Technics range from the application of two-pad electrodes with the trunk sandwiched between them, to the application of cuffs to the legs and lower abdomen In addition, various types of air-spaced electrodes are used These are placed over the chest and abdomen with an air space of approximately two inches between the patient's skin and the active portion of the electrodes The condenser field has a decided advantage over conventional diathermy as far as simplifying technic and lessening the danger of severe burns.

The latest method of inducing artificial fever, and in our opinion the best, is by means of *the induction field*. To generate the high frequency induction field, a vacuum tube oscillator, called an *Inductotherm*, generating an alternating current having a frequency of approximately 10,000,000 to 15,000,000 cycles per second, is used. As has been already shown, a frequency of this order of magnitude is to be preferred for induction heating of tissues. The current is conducted through a flexible, heavily insulated cable, which is wound into a coil of one or two turns and placed under or over the patient's body, with requisite spacing to assure maximum transfer of energy.

In our opinion, it is desirable to produce maximal heat in the vascular rather than in the adipose tissues. The production of

excessive heat in the subcutaneous fat during the administration of high frequency currents by conventional diathermy is an important cause of the discomfort experienced by many patients The induction field, which heats tissues in direct proportion to their conductivities, as we have shown, provides a means for the more comfortable treatment of patients, especially those having an unusually large amount of subcutaneous fat.

Formerly patients were treated in an ordinary hospital bed, using blankets or a specially designed treatment bag for heat insulation. Now, however, air-conditioned cabinets are combined with the induction field for the production of fever. Since this, in our opinion, represents the method of choice, the technic which follows will be that of this method.

PREPARATION OF THE PATIENT. Before prescribing artificial fever, the physician should decide whether it has any therapeutic value for the disease. Lack of confidence on his part in the efficacy of the treatment is usually unconsciously transferred to the patient.

The treatment causes variable degrees of discomfort, because the patient is hot and above his usual narrow range of body temperature. Some patients do not tolerate heat, in general, as well as others.

The discomfort will also vary with the method employed to raise the temperature. Patients should be prepared for some expected discomfort, but it should not be emphasized to the point of making the patient unduly apprehensive They should be made to realize that such treatment is not without hazard, but that in qualified hands the dangers are quite remote Such preliminary steps will do much to allay the patient's natural apprehension. Confidence on the part of both physician and patient is the first requisite of success. However, consideration must be given to the contraindications to this form of therapy.

The patient should be given a thorough physical examination and should also be subjected to an electrocardiographic examination. If, in the opinion of the physician, the fasting blood sugar may be low, it is advisable to do a glucose tolerance test in order to determine the possibility of impending hypoglycemic shock

Likewise, the blood calcium should be within its normal range. There should be no impairment of the cardiorenal function. The usual blood and urine tests should be made. Minor heart lesions with compensation are not necessarily contraindications, as was shown by Oshorne, Blatt, and Neymann[36] Patients with evidence of poor vasomotor tone must be treated with caution, and carefully observed for at least twelve hours following their return to a normal temperature after a session of fever Patients who have had heat stroke are grave risks and should not be subjected to this treatment. This is also true of alcoholics

The age limit for patients to be given hyperpyrexia is usually placed at sixty years, but some patients beyond this age may be a good risk, while others at fifty years of age may be extremely poor risks. Patients with hypertension or arteriosclerosis should not be given fever treatment

The patient should be given an enema the evening preceding the treatment, and breakfast on the morning of treatment, if desired, should be light, consisting largely of fluid foods, which normally are evacuated from the stomach within two hours Kopp and Solomon[37] state that they found the absorption of fluid from the gastrointestinal tract was either delayed or impaired during hypertherm treatments Similar observations were made by Dowdy and Hartman.[38]

The injudicious use of narcotics and sedatives must be avoided. The excellent work of Dowdy and Hartman makes this very clear. The entire circulatory system is placed under a marked load during any treatment with artificial fever. The autopsies made by Hartman[39] reveal that patients die largely from anoxemia.

[36] Osborne, S L., Blatt, M L, and Neymann, C. A.. Electropyrexia in Rheumatic Carditis, Chorea, and Certain Other Childhood Diseases Physiotherapy Rev 18 68 1939

[37] Kopp, I, and Solomon, H C Shock Syndrome in Therapeutic Fever Arch Int Med 60 597 1937

[38] Dowdy, A H., and Hartman, F W · Preparation of Patients for Fever Therapy with Special Reference to Sedation and Fluid Intake, Abst. and Discuss First Int Fever Conf Paul B Hoeber, Inc, New York, 1937

[39] Hartman, F. W Lesions of Brain Following Fever Therapy, Etiology, and Parthogenesis J A.M A 109 2116 1937.

He states that the sedatives used undoubtedly are a partial cause of this oxygen deficiency, as similar results can be produced by these agents alone Dowdy and Hartman advise the use of sedormid because it has a greater margin of safety than the barbiturates The evening before the treatment, their patients are given a high carbohydrate meal, and in the case of well developed adults 8 to 12 grains of sedormid at bedtime The following morning at 6:30, another 8 to 12 grains of sedormid is administered Then 500 cc of 10 per cent glucose in physiological saline are given intravenously. At 7.00 A M the patient is given breakfast consisting of toast and tea At 7:30 A M another dose of sedormid consisting of 4 to 12 grains is given The sedative is given orally in tablet form During the treatment these workers administer by mouth an Iced solution containing 3 per cent dextrose and 0 6 per cent sodium chloride

Kopp and Solomon state that "artificial fever, induced by high external temperatures with the prevention of loss of heat, is an ideal dilator of the capillaries" It will therefore be apparent that the use of drugs which might add to this burden should be given careful consideration. While many sedatives produce dilatation of the blood vessels, some affect the vessels less than others Hyoscine, or any drug that inhibits secretions, should not be used The use of such drugs can precipitate heat stroke by inhibiting perspiration

Neymann, Blatt, and Osborne[40] reported that no sedatives were used during the treatment of their chorea patients Instances arise, however, when sedatives are indicated and can advantageously be used, but it is our opinion that the tendency is to use narcotics far too freely. In our researches, after experimenting with many sedatives, we have come to limit ourselves to the use of either morphine sulfate or Pantopon for the initial dose If this proves ineffective, it can be repeated later We never give more than 0 02 Gm (1/3 grain) morphine sulfate during any one treatment

For patients exhibiting a slow pulse, hypotension, easy fatiga-

[40] Neymann, C A, Blatt, M L, and Osborne, S L The Treatment of Chorea Minor by Means of Electropyrexia J.A M A. 107 938 1936

bility, and subnormal temperature, Schmitt, Holmquest, and Marshall[41] advise an adequate fluid intake combined with from 10 to 15 Gm. (⅓ to ½ ounce) of sodium chloride in the 24 hours preceding treatment, as well as several hypodermic injections of adrenal cortex during the week preceding treatment If this medication is helpful, its use is continued in the interval between fever treatments. Cowles[42] uses a similar technic.

According to Brown, Clark, Jones, Walther, and Warren,[43] the incidence of collapse during artificial fever therapy can be greatly reduced by the judicious replacement of water and sodium chloride lost in sweat. The development of collapse was found by them to be associated with dehydration and, occasionally, overhydration of the blood plasma. Therefore, in their opinion, there is need for a guide to control the water and salt intake They suggested measurement of the plasma specific gravity prior to and during the treatment.

Edelmann and his co-workers[44] investigated the effect of adrenal extract in alleviating the weakness, nausea, vomiting, and herpes often accompanying hyperpyrexia. They studied twelve subjects suffering from syphilis of the central nervous system. The patients were treated once a week for ten weeks Adrenal extract 6 cc. was injected intramuscularly immediately after the first sample of blood was withdrawn and 4 cc. after the patient was removed from the cabinet. During control periods placebos were injected. It appeared that adrenal extract prevented or reduced the fall in plasma sodium in some instances, had no effect on plasma potassium and may or may not have affected the plasma chloride. After one or two treatments, there appeared to be a marked reduction in fatigue with an accelerated rate of recovery. Fever treatments

[41] Schmitt, M G, Holmquest, H J, and Marshall, J G Fever Therapy Physiotherap Rev 16.93 1936

[42] Cowles, D S · Personal Communication.

[43] Brown, H R, Jr, Clark, W F, Jones, N, Walther, J, and Warren, S L The Relationship of Dehydration and Overhydration of the Blood Plasma to Collapse in the Management of Artificial Fever J Clin Invest 22 471 1943

[44] Edelmann, A, Mahanna, D L, Lewis, L A, Thatcher, J S, and Hartman, F A Use of Adrenal Extract in Fever Therapy J Clin Endocrinology 3 20 1943

with extract were tolerated better than subsequent treatments without it. Although extract favorably affects fatigue and recovery the first time it is used, its effect is greater in subsequent treatments. The blood sugar fell in every instance when extract was not administered. When either extract or desoxycorticosterone was given, the blood sugar rose somewhat. Extract caused a reduction in the concentration of sodium in the sweat The total potassium excreted was reduced in some instances when extract was given The frequency and intensity of the other ill effects were also favorably affected. Desoxycorticosterone acetate had no beneficial effect. In the opinion of these investigators, the retention of sodium, when adrenal extract was given, was insufficient to account for the amelioration of the unfavorable clinical reactions to fever therapy. They suggested that the extract may act on the central nervous system.

Adrenalin should never be used as a heart stimulant, unless it is absolutely a case of life and death Patients may die of respiratory failure before the heart has ceased to beat, hence adrenalin is rarely indicated.

Insulation Against Heat Loss. No matter what method is used, the patient must be insulated against heat loss if an elevation of temperature is to be secured and maintained When external heat is employed, the patient is placed in a specially designed cabinet, with a source of heat constantly applied to make up for any heat loss that might occur. With such treatments, it is usually necessary to anoint the body with some form of oil to protect the skin from burns It is also necessary to apply either a sheet or towels over the entire body when the patient begins to complain of the excessive external heat on the skin Occasionally slight burns do occur, but these are minor and yield readily to appropriate treatment.

When using high frequency current in the form of conventional diathermy, the high frequency electric field, or the induction field, the patient may be placed in a standard bed, in a special treatment bag, or in an insulated air-conditioned cabinet

Use of an Ordinary Hospital Bed A full-length rubber sheet should be placed over the entire mattress for heat insulation Three all-wool blankets are placed over the rubber sheet, with one edge

of the blankets just even with one edge of the mattress and the remainder of the blankets extending down to the floor A soft bath blanket should be placed over the three bottom blankets in the shape of a triangle, with its apex directed to the foot of the bed The base of this triangular blanket should be level with the upper region of the neck The purpose of this blanket is to prevent heat loss around the neck, when the patient is restless Next a layer of terry cloth or absorbent material is placed over these layers and should be large enough to cover the patient The patient is placed in the bed and covered with the terry cloth, taking great care to make the region around the neck as heat tight as possible Then the triangular blanket is brought around the shoulders and tucked snugly about the neck to prevent heat loss at this region The importance of this can be easily understood when it is recalled how readily heat is dissipated from this region of the body Furthermore, if the covering is not kept snug about the neck and shoulders, warm air will escape from around the patient, slowing temperature rise, and making the maintenance of the desired fever plateau difficult The woolen blankets are then folded over the patient, one by one, and a full sized rubber sheet applied over the last blanket. All the blankets are snugly tucked in on the open side of the bed and around the neck to prevent heat loss The patient is now ready for treatment The cable of the induction field generator is placed in an elliptical form of one or two turns over the outside blanket, extending from midchest to approximately the midpoint of the legs Figure 217 illustrates this technic, but with a treatment bag After the electrodes are connected to the machine, the initial temperature, pulse, and respiration should be taken The current is then turned on More blankets may be needed, and if so, can be added Throughout the treatment all openings around the bed and the neck of the patient must be kept closed if temperature is to be maintained

Use of a Treatment Bag There are at least two types of treatment bags on the market in one wool is used between covers of water proofed material, while in the other Kapok is used between covers of gum rubber We have used both types, but favor the wool filled type because of its wearing qualities

The bag is placed symmetrically on a bed with its upper edge reaching to about the place where the occiput of the patient will rest The bag is then opened fully, and the upper portion or that portion which covers the patient, is turned back, and permitted to drape temporarily over the side of the bed A full length rubber sheet is spread over the opened bag and the triangular blanket spread on top as described previously A large terry

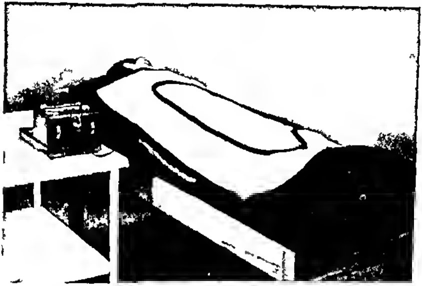

FIG 217 Application of high frequency induction field for production of artificial fever using blankets or treatment bag for insulation.

cloth blanket, folded once, is placed on the rubber sheet with folded edge coinciding with the open side of the bag This arrangement will permit the small zippered opening at the opposite side of the bag to be used for the purpose of taking temperature or making other observations When the patient is placed between the upper and lower halves of the terry cloth blanket, care must be taken that the neck is well insulated to prevent heat loss The bag is then completely closed and fastened with the zipper arrangement The two upper corners of the closed treatment bag should be tucked under the shoulders of the patient The cable

electrode is arranged as shown in Fig 217 For additional insulation, it may be necessary at times to place an additional full length rubber sheet as well as two additional wool blankets over the bag This may be done without disturbing the cable electrode

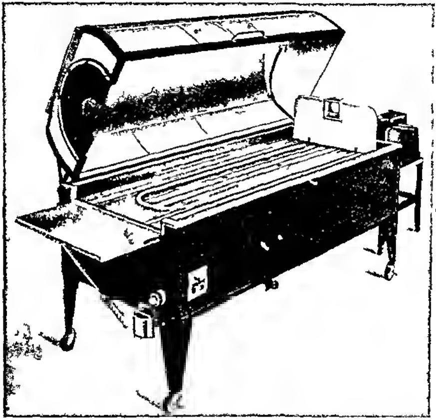

Fig 218 Air conditioned cabinet for use with high frequency induction field *for fever therapy The method of applying the induction cable is shown.*

It is important that all parts of the cable electrode be separated *from the metallic zipper at least 6 inches This can be done* by using a pillow or a folded blanket to support the leads going to the generator If the leads should be in contact with the metallic zipper, sufficient heating of the zipper will result to burn, and possibly ignite, the treatment bag

Fig 219 Air conditioning system of cabinet A Immersion heater B Humidifier water container C Air heater controlled by thermostat D Fan which operates continuously for the purpose of securing uniform temperature of the air within the cabinet

Use of an Insulated Air Conditioned Cabinet In our opinion an air conditioned cabinet, used solely for the purpose of heat insulation, with electromagnetic induction as the means of heat

production, is the most satisfactory method for hyperpyrexia by physical agents in use today The desired temperature plateau, after having been reached by induction heating, is maintained by means of the circulating, warm, humidified air of the cabinet

The cabinet, Fig 218, is constructed of metal and is insulated

FIG 220 (a) Thermostat to control temperature of air within cabinet.

to minimize loss of heat The cabinet is mobile and of ample size to permit reasonable movement of a patient during treatment Sliding doors on both sides of the cover permit access to the patient

The lower section of the cabinet has a separate built in tub The air-conditioning system, Fig 219, consists of two separate electric

heating elements one to evaporate water for the humidification of the air, and the other to heat the air to the necessary level for maintenance of a patient's temperature A fan is installed in the heating unit, which operates continuously to circulate the

FIG 220 (b) Switch for immersion heater and filler cup for water container

heated, humidified air throughout the interior of the cabinet The temperature of the air within the cabinet is controlled by a thermo stat, which operates within the range 80° to 110° F, Fig 220a The humidifying device consists of an immersion type vaporizing unit of 1000 watts capacity, installed in the water container A switch permits its operation on high, medium, or low intensity

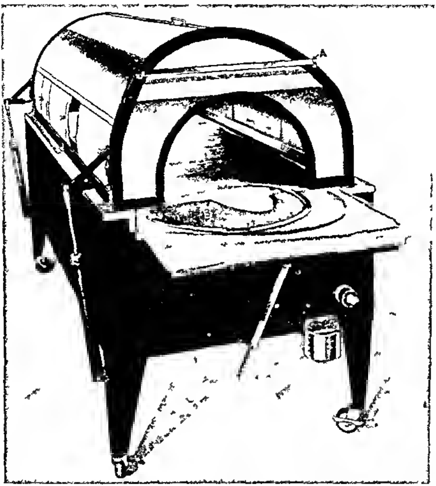

FIG 220 (c) Head end view of cabinet showing towel bar (A) and removable rubber collar (B)

Means to fill and drain the water container from the outside of the cabinet are provided Fig 220b

The *cover of the cabinet consists of double walls*, with insulation material between them to prevent heat loss The cabinet is provided with a removable, *soft rubber collar*, which fits comfortably around the patient's neck, also, a bar to accommodate a towel to be hung and draped about the neck to prevent the egress of warm air from the cabinet, is mounted on the head

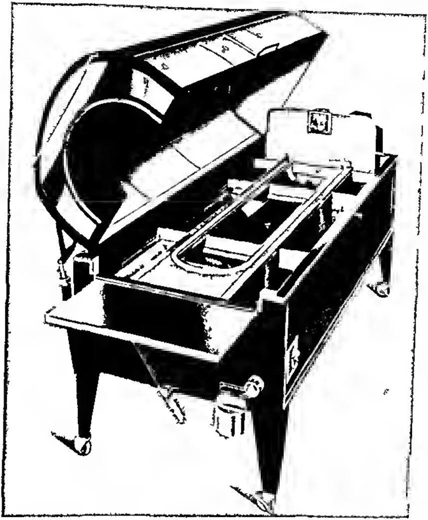

FIG 220 (d) Mattress support with removable sections and foot board on which is mounted a lamp for illuminating the interior of the cabinet when necessary

end of the cover, Fig 220c A thermometer installed in the top of the cover, indicates the temperature within the cabinet

The patient s mattress support is of wood and is divided into removable sections for easy access to the lower section of the cabinet for the purpose of cleaning An appropriately shaped

groove in the supporting frame positions the induction cable into a coil of one turn of such dimension that the entire body of the patient is subjected to the induction field A foot board is provided to protect the patient's feet against the warm air arising at the end of the cabinet and to direct the circulation of the warm air. The treatment chamber can be illuminated, when desired, by means of a light provided for that purpose Fig 220d

The cabinet is equipped with a mattress of adequate thickness and resilience to assure comfort The mattress extends the full length of the treatment chamber and out onto the head rest. The head rest is of metal, is adjustable, and is large enough to accommodate a large pillow for the patient's comfort

TECHNIC OF TREATMENT WITH CABINET AND INDUCTION FIELD

Preparation of Cabinet

1 Prepare mattress of cabinet as follows. Cover with a rubber sheet the size of the mattress; then with two terry-cloth blankets Secure the blankets and sheet in position Replace the mattress in the cabinet, so positioning it that the zipper which closes the mattress cover is at the head-end Now close the cabinet, and place a pillow over the opening in the head end to prevent the escape of heated air

2 Fill the humidifier pan with water through the filler cup at the head end of the cabinet to the level indicated It is important that the water be kept at the proper level throughout the treatment Fig 220b *The immersion heater must always be kept covered with water during its operation If operated without water, the heating elements will burn out, necessitating an expensive replacement.*

3. Set the thermostat control, Fig 220a, at 110 degrees by turning the knob until the arrow coincides with the 110 degree graduation on the dial

4. Set the humidity heater switch, Fig 220b, on "high"

5. Turn the master switch, Fig 220e, to the "on" position Allow the cabinet to operate until the temperature for which the thermostat was set has been reached

Fig 220 (e) Master switch p lot l ght and switch for cabinet l ght.

Administration of Treatment

1 Lock the casters so that the cabinet will not roll and then place the patient in the cabinet Throughout the induction period the patient should lie flat on his back with legs stretched out Fig 221 Should he lie on his side or on his back with his knees drawn up the time required to elevate his temperature will be increased because of the fact that a smaller mass of vascular tissue is subjected to the effective portion of the induction field The master switch is left in the "on position and the thermostat left set at 110 degrees The setting of the humidity switch how

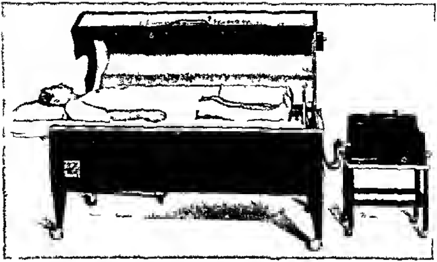

Fig 221 Patient properly positioned in cabinet

Fig 222 Towel draped over towel bar and around patient s neck to minimize egress of heated air from cabinet

ever, is reduced to 'medium The Inductotherm is now turned on, with intensity control set at 100 A bath towel is placed over the towel bar and the ends allowed to drape over the patient s

INDUCTOPYREXIA RECORD

CASE NUMBER________ NAME________ AGE___ SEX___ DATE_____

D AGNOS S________ T________ TREATMENT____ SERIES_____

PHYS C AN________ REFERRED BY________ NURSE________

HOUR	EMPERA R		PULSE	# SP	M DICATION	INT KE	REMARKS

Fig 223 Nurse s record of fever treatment

neck, Fig 222 This will effectively prevent the patient from being forced to breathe warm air from the cabinet which might escape around the neck piece Pulse respiration and rectal temperature are to be taken and recorded every fifteen minutes on

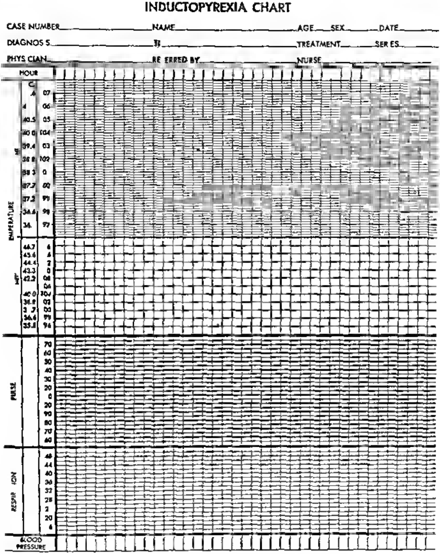

FIG 224 Chart of fever treatment

charts such as those illustrated in Figs 223 and 224

2 Operate the cabinet as described above for about 15 minutes Then turn the humidity switch to 'low, and proceed with the treatment If the rise in the patient s temperature exceeds one degree per 15 minutes turn Inductotherm off The rate of rise

of the patient's temperature is determined in general by the rate of energy input into the patient from the Inductotherm To decrease the rate of rise, operate the Inductotherm at a lower intensity setting

3 When the patient's temperature reaches a point within two degrees of the final temperature desired, reduce the thermostat setting to correspond to the final rectal temperature desired in the patient

4 When the patient's rectal temperature reaches a point within one degree of the final temperature desired turn the Inductotherm off, and at the same time reduce the thermostat setting to 90 degrees Observe closely the rate of temperature rise by taking rectal temperature readings every five minutes The patient's rectal temperature usually rises one degree after the Inductotherm is turned off

The rate of increase in temperature during the *coasting* period is usually the same as that during the induction period that is, about one degree in 15 minutes

5 Toward the end of the coasting period there is usually noted a definite slowing up of the temperature rise At this point, advance the thermostat setting to the final rectal temperature desired From then on, the cabinet temperature can be balanced against the rectal temperature so as to maintain a level plateau It may be necessary to make slight changes of the thermostat setting every 15 to 30 minutes to maintain a perfectly level plateau Seldom is it necessary to use a cabinet temperature in excess of the rectal temperature The cabinet temperature required for the maintenance of fever is usually one to three degrees lower than the patient's rectal temperature

6 Should there be no rise in temperature during the coasting period, turn the Inductotherm on until the desired temperature plateau is reached When the proper level is obtained and the use of the Inductotherm is terminated discontinue the use of the clinical thermometer and insert the bulb of the electric indicating thermometer and continue to record the rectal temperature, pulse and respiration every 15 minutes It is of paramount importance that the trend of the temperature be under constant supervision

The use of an electric indicating thermometer makes this possible. *Caution: Do not use or permit the sensitive bulb and the lead of the electric thermometer to remain in the cabinet while the Inductotherm is "on."*

Temperature and Temperature Control The only safe procedure is to rely on rectal temperature readings, no reliance can be placed upon mouth or axilla temperature readings. While using the high frequency current, one must use the ordinary clinical thermometer for taking temperature, because electric thermometers are influenced by high frequency fields, and hence give spurious readings. However, when the high frequency field is no longer in use, then the clinical thermometer may be replaced by an electric indicating thermometer. This we believe to be very important for the safety of the patient. The most critical period of treatment is after reaching the fever plateau It is then that the trend of the temperature gradient needs to be kept constantly under observation. A resistance thermometer, Fig 225, is sufficiently accurate and follows the temperature gradient quickly with very little lag We believe that it is unsafe to do fever therapy without the use of some such temperature-indicating device.

While maintaining the temperature plateau, the cabinet temperature should be regulated according to the trend of the patient's rectal temperature If the rectal temperature remains stationary after the induction period is finished, then the cabinet temperature is kept at the level which obtained during the latter part of the induction period; but if, as is usual, the rectal temperature rises, then the cabinet temperature is correspondingly lowered. The cabinet temperature is varied, therefore, as one would vary any insulation covering the patient.

Should it be impossible to maintain the patient's temperature with a cabinet temperature of 110° F., the difficulty is probably due to faulty technic—such as the escape of too much heat from the cabinet in the region of the neck, or to faulty technic in the operation of the cabinet. We find that we can operate a cabinet of this description at a temperature of 100° F. to 110° F , usually at approximately 105° F. The air within this cabinet when

maintained at a temperature of 98° to 110° F., shows a relative humidity of approximately 100 per cent.

The ideal technic is that which permits maintenance of desired rectal temperature level with the lowest cabinet temperature. Lowering the cabinet temperature, therefore, is the best possible

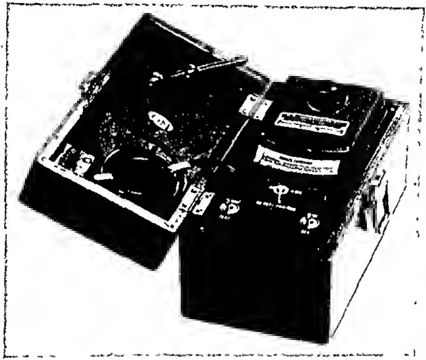

FIG. 225. Indicating resistance thermometer for fever therapy

method for cooling the patient when necessary. Another method of cooling the patient is to operate a fan so as to blow a current of air across the face and head, or to apply cloths wrung out (not too dry) in ice-cold water to the head and face, or even a combination of both methods. Both of these procedures impart marked comfort to a patient undergoing fever therapy and hence are frequently used for that purpose. It must not be forgotten, however, that these procedures will definitely lower body temperature and if persisted in will result in inability to maintain a

constant temperature plateau Fever is not, nor cao ever be made a wholly comfortable experieoce, for the temperature of the patient has been purposely elevated to a level to which he is oot physiologically adapted To promote comfort at the expense of temperature is to defeat the purpose of the treatment These measures must not be carried to the point where the temperature will drop too rapidly Just as soon as the trend downward begins to be indicated, it is wise to stop these procedures until the down ward trend stops Then, if the temperature is still too high, the applications may be repeated It must be uoderstood that there will not be an instaotaoeous response to these measures

If the temperature continues to rise despite these steps, the next procedure would be to open the doors of the cabinet gradually If this proves ineffective, then the cabinet should be opened with the patient completely exposed If the tempera ture gets out of control and must be reduced quickly, it is best accomplished by keeping the surface of the body wet with lukewarm water and having one or two fans blowiog over the entire body surface Immersing in cold water serves to further constrict the surface capillaries and interferes with the loss of heat

THE NURSE'S RECORD Blood pressure should be recorded at the beginning and at the end of the treatmeot Rectal tempera ture, pulse and respiratioo should be recorded at least every 15 minutes The nurse should note and record the onset of perspiration, also the appearaoce of cyaoosis, dyspnea, irregularity in regard to rhythm and amplitude of the pulse, circumoral pallor, restlessness of the patieot, aod aoy irrational or slurring speech, should such effects occur In additioo any aboormality in the mental state of the patient should be observed and recorded The nurse should record cabinet temperature throughout the entire treatment, and also the time of turoiog on and off the high fre quency field The patient's fluid intake should be recorded as to the amount and time of administration What drugs or medication are employed should also be indicated, Fig 223 A fever chart similar to that shown in Fig *226* should be plotted

CARE OF THE PATIENT DURING TREATMENT As soon as the treat

ment is started, a nurse must give her undivided attention to the patient, for a great deal depends upon the confidence she may be able to instill in the patient It is necessary that she be of a sympathetic disposition, yet capable of being firm whenever necessary Arthritic patients, who are unable to extend their knees completely,

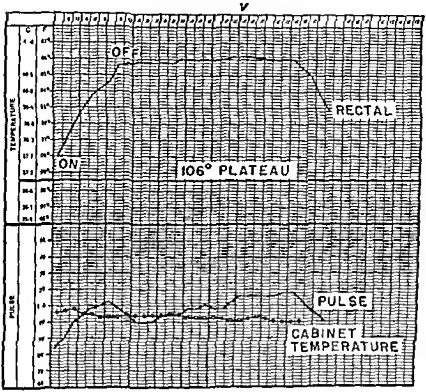

FIG 226 Chart of a hyperpyrexia treatment

should have a pillow or small blanket roll placed under the knees to prevent strain and discomfort at the knee joints

Perspiration appears soon after the beginning of the treatment, and should be constantly wiped from the face with a cool, damp face cloth The patient will begin to feel uncomfortable as his temperature rises, the maximum discomfort usually occurs when the temperature is between 102° F to 103° F An occasional patient may become so restless at this point that it might be well

to lower the intensity of the high frequency field until the patient becomes less restless This condition is probably brought about by a too rapid temperature increment, and it is doubtful whether this should be combatted by lulling the patient to sleep with a narcotic

Restlessness is undoubtedly a physiological response and might be due to an endeavor on the part of the body to force blood from the peripheral bed back again into the larger vessels to maintain an adequate circulation If so, it is still another reason for abstaining from the indiscriminate use of sedatives Sedatives are necessary at times, and when necessary, should be used Our investigations seem to indicate that when a sedative is necessary, the most effective time for its administration is as soon as the high frequency induction field is discontinued At that time the patient is apt to be more responsive to a minimal dose than at any other time He can be told that his temperature has reached the desired level, and now must be maintained for a required number of hours and that he should endeavor to sleep As far as possible, we always try to avoid the giving of sedatives during the height of the fever

We do not find that morphine, administered in the doses recommended by us, produces nausea and vomiting It is our belief that nausea and vomiting are more frequently the result of undigested food in the gastrointestinal tract, the lack of sodium chloride in the drinking water, or because the fluids ingested are not absorbed If fluids are continually administered and are not absorbed, the stomach becomes distended, and finally, tolerating no further insult, it evacuates its contents The patient who is unable to absorb fluids readily will naturally crave water, and far more intensively than one whose absorption is unaffected In such cases the fluid intake should be limited to 150 200 cc each 15 minutes, not all of it, however, should be given at one time, but only about 50 cc every 5 minutes This serves to allay somewhat the craving of the patient for water In all cases, the total fluids administered during a treatment should not exceed four liters Each patient, however, is an individual problem and must be dealt with as such

In each liter of water, 6 Gm of sodium chloride are dissolved, or 90 grains per quart At this concentration it is not unpalatable, and provides adequate sodium chloride to replace the chloride loss by perspiration Salt administration will frequently eliminate nausea and vomiting. In the case of children, we alternate the salt water with fruit juice, to which some form of sugar has been added. Some patients will tolerate and enjoy clear soup, coffee, or tea, and occasionally children can be given an orange, provided it is not eaten all at one time

No matter what type of thermometer is used, it should never be inserted by the patient When the usual clinical thermometer is used, it should *remain* in the rectum constantly and only be removed for reading When the electric indicating thermometer takes its place, the position of the rectal applicator of the thermometer should be checked from time to time to make sure it is properly in place The rectal insert is provided with a rounded or pear-shaped enlargement, which must pass the external sphincter muscle of the anus Unless the bulb is correctly inserted, the instrument will not indicate correctly Furthermore, the bulb must be properly inserted with the enlargement passed beyond the external sphincter in order that it be firmly retained in position. Whenever it is necessary to place the thermometer in the rectum or to remove it, or to supply the patient with a bedpan or urinal, it should be done in such a way as to minimize heat loss from the cabinet The bedpan should always be heated before being given to the patient It is only by constant attention to such details that one can maintain a fairly uniform temperature level over many hours

Friends and relatives should not be permitted to visit the patient during the treatment, since they do not understand the procedure and often disturb and worry the patient The room should be well ventilated and darkened to make conditions as conducive to sleep as possible Noise and confusion should be carefully avoided

The physician under whose supervision the treatment is being given, should not only be readily accessible at all times until the complete termination of the treatment, but should visit the room

frequently to show his interest in the welfare of the patient. It is an excellent plan for the physician, referring the patient to the fever department for fever therapy, to visit the patient after the fever has been induced, thereby imparting assurance and confidence to the patient.

TERMINATING THE TREATMENT When it is time to terminate the fever at the end of a successful treatment, the patient is lightly covered with a sheet, and the cabinet is opened All soiled linen under the patient is replaced with a clean sheet, and his temperature is permitted to return to the normal level A light blanket is placed at the feet, with instructions for it to be used whenever the patient feels its need It usually requires one hour to one hour and a half for the temperature to fall from 105° F to 100° F. When the rectal temperature reaches 100° F., the patient is given a tepid sponge bath, followed by an alcohol rub, and is placed in a freshly made bed and returned to his room The patient is not permitted to sit up at any time until the following morning When the patient is returned to his room, he may be given any food he might desire His temperature should be taken every third hour during the night to be sure that no secondary temperature rise occurs

WARNING SIGNALS The nurse should be made thoroughly familiar with all the danger signs which indicate that the temperature should be lowered or the treatment terminated As a general rule, the patient's temperature should not rise more than one degree during each 15-minute interval, if the increment exceeds this, it frequently places too great a load on the circulation. This is evidenced by a rapidly rising pulse rate, dyspnea, marked restlessness, the appearance of circumoral pallor, and a feeling of apprehension.

These symptoms can usually be checked by slowing the rate of temperature rise to permit physiologic adjustment to take place With a too rapid temperature rise, particularly in diseases affecting the central nervous system, there is the added danger of the temperature not staying within the limits of safety and precipitating heat stroke A patient whose temperature is quite difficult to keep under control—that is, within 0 2° F. plus or

minus—by the usual method must also be watched with care Patients who show poor vasomotor control should not be subjected to temperatures of 104° F, unless the physician is certain that the patient will tolerate this temperature for the requisite period It is better to give the first treatment at about 103° F. for four or five hours. In succeeding treatments gradually increase the time and the height of the temperature until 104° F for the requisite period has been reached. Such patients should not exceed a temperature of 104° F, and their temperature should at no time be reduced too abruptly. A patient who shows signs of circumoral pallor at any time should be watched carefully, for this is a signal of some circulatory embarrassment If it becomes pronounced, the treatment should be discontinued

A steadily falling pulse rate with a sustained high temperature, or an irregular pulse combined with marked differences in amplitude, are also signs which must not be passed over without due consideration There is almost always some slight degree of cyanosis present, and unless it becomes quite marked, is without great significance A marked diminution or cessation of sweating should be carefully noted, for this might indicate approaching heat stroke A patient who does not perspire readily is more susceptible to heat stroke The appearance of an almost imperceptible twitching around the lips or fingers is a signal to discontinue the treatment Such twitchings may be the incipient symptoms of impending convulsions It is particularly important to watch for these disturbances when treating children

Another sign calling for careful attention, is an unusually rapid respiration, or a respiration which is irregular in amplitude and rate Respiration fails before heart action A patient showing evidence of mental confusion at a temperature of 105° F, or below, should not be continued under treatment Treatment should be immediately discontinued when systolic blood pressure drops below 80 mm Hg, or when the pulse pressure is less than 20 mm Hg

TREATMENT OF UNTOWARD EFFECTS *Heat Stroke* All covering should be completely removed from the patient and cooling measures instituted The body surface, especially in the region of the

head, neck, and chest should be sprayed and kept moist with cool water while evaporation is hastened by an electric fan The evaporation of water at body temperature (98 6° F) carries away 575 5 gram calories per gram of water evaporated, while the melting of ice removes only 80 gram calories per gram of ice melted Applications of ice-cold water cause constriction of the surface capillaries and interfere with the loss of heat Therefore, the loss of heat by evaporation of surface moisture would seem to be a more physiological method of cooling the body If these measures fail, it is necessary to resort to a complete tub bath

Circulatory Failure or Shock The patient is cooled as rapidly as possible in the manner described in the previous paragraph Intravenous infusions of normal saline solutions and five per cent glucose solution in amounts ranging from 500 to 1500 cc should be given However, the danger of overburdening the circulation with the production of pulmonary edema should be kept in mind Kopp and Solomon[45] advise repeated determinations of the venous pressure to prevent this danger Respiratory embarrassment should be combatted with the application of oxygen and five per cent carbon dioxide inhalations This is an ideal respiratory stimulant, supplies the body with carbon dioxide to compensate for the alkalosis, reduces cyanosis, and lessens capillary permeability by relieving the anoxemia

The loss of carbon dioxide by the body through the lungs and sweat during the fever is undoubtedly an important factor in increasing the alkalinity of the blood Through the skin there is a carbon dioxide loss of some importance Koehler[46] is of the opinion there is a direct correlation between cyanosis and certain types of alkalosis Mild cyanosis is not an uncommon occurrence in fever therapy Koehler believes that fever alkalosis is due to increased lung ventilation and the rapid elimination of carbon dioxide from the blood, thus causing a carbon dioxide deficit, which in turn results in the passage of sodium ions into the tissue

[45] Kopp I and Solomon H. C Shock Syndrome in Therapeutic Fever Arch Int. Med. 60 597 1937

[46] Koehler A E Acid Base Equilibrium I Clinical Studies in Alkalosis Arch. Int Med 31 590 1923

lips; occasionally, however, they also appear on buccal mucosa, and less frequently on the nares

Warren, Carpenter, and Boak[53] reported that 46 2 per cent of their 411 patients developed a herpetic corneal ulcer, which made an uneventful recovery They state it is not clear whether the disease develops as a result of some change in the resistance of the host, caused by the primary infectious agent, or by the elevation in temperature Neither the degree of temperature elevation, nor the duration of the fever, had any direct relationship to the occurrence of the herpes It is probable that the virus is carried by the patient An explanation of the development of herpes at the present time is cell trauma In the case of artificially induced fever, elevation of the skin temperature may in some manner alter the cell nucleus, thereby giving rise to a new agent which can be recovered from the resultant lesions as a filter-passing virus Warren, Carpenter, and Boak state that the lesions were usually confined to the skin about the mouth and nose, and appeared most frequently on the mucous membranes of the lips, near the mucocutaneous borders, following in general the distribution of the fifth cranial nerve

It is advisable to inform the patient of the possibility of the formation of the so-called *fever blisters*, so that he may not be unduly alarmed if they should appear For treatment some use topical applications of 50 per cent alcohol as soon as the vesicles appear. The application of lanolin or cold cream to the blisters has been found to be useful by others The frequent use of sulfathiazole ointment affords a protective coating, which relieves some of the distress of herpetic lesions and will prevent or control the secondary infection which is often associated with these lesions

In our experience, herpes simplex has never occurred with such intensity as to cause interruption of a course of treatments

IV. THERAPEUTIC APPLICATIONS As stated in the Preface, it is not our intention to discuss therapeutic applications Hence, no attempt will be made to discuss or evaluate the merits and limita-

[53] Warren, S L, Carpenter, C M, and Boak R A Symptomic Herpes A Sequela of Artificially Induced Fever J Exp Med 71 155 1940

tions of artificial fever in the wide range of conditions in which it has been employed. The literature on the subject is very extensive. We have summarized in Table 61 those conditions in which fever has been found useful, together with temperatures, duration of treatment, number of treatments, and frequency of treatments that have been found effective For an extensive survey of the clinical applications of fever therapy, the reader is referred to the book by Neymann, *Artificial Fever*, published by Charles C Thomas, Springfield, Illinois.

TABLE 61

SUMMARY OF INDICATIONS AND TECHNIC FOR HYPERPYREXIA BY PHYSICAL AGENTS

Disease	Rectal Temperature		Duration in *Hours*	Approximate No of Treatments	Frequency of Treatments	Selection of Cases
	°F	°C				
1 Arthritis	103 104	39 4–40	4–8	8 20	weekly	Infectious (rheumatoid proliferative)
2 Asthma	102 104	38 9–40	6–8	2	3 days apart	Intractable bronchial asthma
3 Brucellosis (Undulant fever)	105 8 107 6	41–42	1 3	2	weekly	Acute and chronic Used in conjunction with sulpha-drugs
4 Chorea	104	40	8	4	bi weekly	Sydenham s chorea
5 Corneal Ulcer Acute Iritis	104 5 106	40 3–41 1	5	2	bi weekly	
6 G C Arthrit s	106 7	41 5	6 8	4	2 3 per week	Acute or chronic
7 General Paresis	Above 103 5 106	Above 39 7 41 1	6 2 Total 8	20	b weekly	Early cases and those not too badly demented
8 Gonorrhea	106 7	41 5	6–8	4	2 3 per week	Intolerant of or resistant to sulpha drugs
9 Gonorrheal Ophthalmia	106 7	41 5	5	2	bi weekly	Acute
10 Mult ple Sclerosis	103 5 105	39 7–40 6	8	20	weekly	Not too far advanced
11 Syphil s	105 106	40 6–41 1	8	5	weekly	Primary and secondary Used in conjunction with chemotherapy
12 Tabes	Above 103 5 106	Above 39 7 41 1	6 2 Total 8	20	bi weekly	Not too far advanced

PART D HIGH FREQUENCY CURRENTS

SECTION SIX PHYSIOLOGY OF ARTIFICIAL FEVER BY PHYSICAL MEANS

I A Comparison of the Effects of Hyperpyrexia Induced by the External Applications of Heat and by the Use of High Frequency Current

Broadly speaking, all of the technics for the production of artificial fever by physical agents can be classified under two general methods

One method uses external heat, which can be applied by electric blankets cabinets using hot air, nebular spray cabinets conditioned air cabinets, cabinets using either infrared generators or incandescent lamps, as the source of heat, and hot water baths The production of the fever is dependent upon the patient being in a heated environment The deeper tissues of the body are slowly heated by the conduction of heat from the heated surface tissues

The other method uses high frequency electric energy to generate heat in the tissues themselves, independently of any external application of heat, for the purpose of producing fever In both methods it is necessary to retard heat loss from the body as effectively as possible so that the patient s temperature can be maintained at a requisite level In addition with such insulation the desired temperature plateau is reached with a minimum loss of time As already pointed out, the methods of retardation of heat loss have evolved from the ordinary hospital bed using rubber sheets and many blankets to the use of a well insulated sleeping bag and finally to the air conditioned cabinet

Unfortunately, very few investigations comparing these two methods have provided objective evidence The question as to whether clinical results could be secured was a far more important question than the *how* and *why* of the various methods in use Most investigators were too busy perfecting their own particular method to experiment with other procedures Most of them were quite satisfied that their own particular technic was the method of choice

After one has used the two methods on a number of subjects it becomes evident that they differ in regard to the intensity of the reactions produced When heat is externally applied the subject is more restless delirium is more frequently encountered and vascular collapse and heat stroke are more likely to occur This clinical impression was formed after several hundred treatments in which both methods were used Osborne[1] conducted a series of investigations to ascertain the explanation and studied a number of physiological responses to fever produced by the two methods

[1] Osborne S L Physiology of Hyperpyrexia Dissertation for Doctorate Northwestern University Evanston 1940

The Effect of Heat Applied by the Two Methods on Axillary and Rectal Temperature. Normally the axillary temperature is below that of the rectum. When heat is applied to the skin, the skin temperature is obviously raised. Fig. 227. For this reason it was considered advisable to determine the axillary and rectal temperature changes when fever is produced by the two methods.

It is to be noted that when internally generated heat is employed for raising the body temperature, the normal temperature gradient is maintained from the start to the finish of the treatment, as evidenced by the fact that the rectal and axillary temperature curves never cross. Conversely, with the use of external heat a reversal of this normal temperature gradient is present during the induction of the fever. But when the fever plateau has been reached, the normal temperature gradient reasserts itself, and does not change again, provided the patient is well insulated against heat loss. Thus, fever produced by high external temperatures causes a reversal of the normal heat gradients of the body during the induction period, but once the fever plateau has been reached, the normal temperature gradient reasserts itself. However, if it becomes necessary to reapply heat because of a falling temperature, reversal of the temperature gradient will again occur.

The Effect of High Skin Surface Temperature on the Sweat Glands. It was thought that a high skin surface might cause paralysis of the sweat glands and in this manner precipitate heat stroke. Luschsinger[2] reported that if one hand is held in water at a temperature of 45° to 50° C. (113° to 112° F) for 20 minutes, and then the two hands are exercised, the unheated hand will begin to sweat much sooner than the heated hand A series of experiments to evaluate the validity of this observation was conducted, but no evidence of sweat gland paralysis was obtained. It was concluded that heat stroke from external heat could not be attributed to the paralysis of the sweat glands. Wiggers[3] states:

"In exposure to high external temperatures, as exemplified by

[2] Luschinger, B · Die Erregbarkeit der Schweissdrusen als Function ihrer Temperatur Arch f d ges. Physiol 18 478 1878

[3] Wiggers, C J : Physiology in Health and Disease Second Edition Lea and Febiger, Philadelphia, 1937.

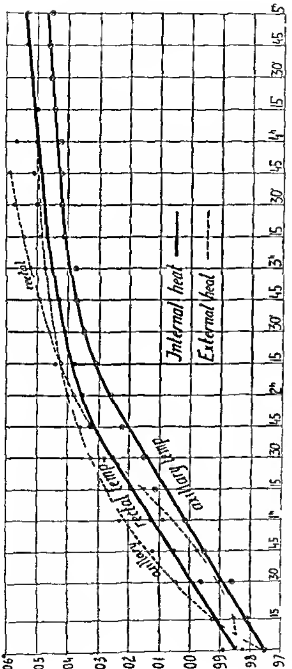

FIG 227 Effect of external and internal heating methods on axillary and rectal temperatures Temperature gradient normal with internal heat reversed with external heat

hot baths, the temperature gradient is either decreased or, in the case of temperatures higher than those of the body, it is actually reversed, so that heat passes from the surrounding medium to the body. The reactions which occur consist of dilatation of skin vessels, partly through action of an increased temperature on nervous centers Heat tends to increase the formation of vasodilator substances in tissue (H substances), these cause dilatation of capillaries and venules directly, and relaxation of arterioles by axon reflexes At still higher temperatures the increase in such instances becomes so great that endothelial permeability is reduced "

The Effect of External and Internal Heat on Water Balance While most workers in the field of hyperpyrexia state that patients lose weight during treatment, no data were published on the actual weight loss until Neymann and Osborne published their data in 1934 [4]

Lepore[5] in 1935 presented a paper before the Fifth Annual Fever Conference on chloride and water balance during artificial fever produced by external heat He reported that the average fluid intake for the treatment, with a temperature of 103° F to 106 7° F maintained for seven hours, was 93 cc per kilo body weight, and the average sweat output 56 cc per kilo body weight The total sweat eliminated, Lepore found, was not related to the degree of fever The sweat output varied a great deal from patient to patient, and in the same patient on different days The average sodium chloride content of the sweat was 5 87 grams per liter Again, individual variations were found to be great. Lepore states that the average patient had a fluid intake of 5300 cc, and lost 3200 cc of sweat and 18 8 grams of NaCl during a single treatment

In 1938 Gibson and Kopp[6] presented a valuable paper regard-

[4] Neymann C A., and Osborne, S L. The Physiology of Electropyrexia Am J Syp & Neurol *18 28 1934*

[5] Lepore, M J Chloride and Water Balance in Patients with Artificial Fever Abst and Papers and Discussion Fifth Annual Fever Conference Dayton Ohio, 1935

[6] Gibson, J G, and Kopp I Studies in the Physiology of Artificial Fever

ing blood volume and water balance during hyperpyrexia treatment. The same year Kopp and Solomon[7] published their article *Shock Syndrome in Therapeutic Hyperpyrexia.* For the first time ample evidence was presented to account for the more frequent occurrence of shock or vascular collapse when high external temperatures are used to produce artificial fever. Both of these papers are valuable contributions, because they tend to clarify some of the hitherto obscure physiologic changes occurring during the course of artificial fever.

Osborne[8] in 1940 presented further data on the weight loss of patients undergoing treatment by means of external and internal heat. Data of forty-five experiments were presented The environmental temperature used in fourteen of the experiments ranged from 100° F. to a maximum of 110° F. A high environmental temperature ranging from 130° F. to 160° F. was used in thirty-one experiments. Total weight loss was calculated from the amount of weight loss during treatment, plus the weight gained by fluid intake, and minus the weight lost through fluid output. This represented the total fluid lost by the body. The water was lost chiefly through evaporation from the skin and lungs Total weight loss during treatment was taken as the actual weight difference before and after treatment, without regard to the water intake or output The average total weight loss was found to be 5 4 kgms with high environmental temperatures, and 3 9 kgms. with low environmental temperatures. The difference of 1.5 kgms. was found to be significant. Table 62.

So far as weight loss and fluid intake and output are concerned, it would appear that the principal difference between these two methods lies in the large amount of fluids demanded by the body when high environmental temperatures are used With externally applied heat, the fluid demand was 157 per cent

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I Changes in the Blood Volume and Water Balance J Clin Invest 17 219 1938

[7] Kopp, I, and Solomon, H C Shock Syndrome in Therapeutic Fever Arch Int Med. 60 597 1937

[8] Osborne, S L. Physiology of Hyperpyrexia, Dissertation for Doctorate, Northwestern University, Evanston, 1940

greater, while the urine output increased only 112 per cent. The average total weight loss for external heat was 5 4 kgms, while for internal heat it was 3.9 kgms

In their paper on shock during therapeutic fever, Kopp and Solomon[9] presented some interesting data on shock reactions which occurred while using the *Kettering Hypertherm*, a device employing external heat. They found a reduction in the volume

TABLE 62

SUMMARY OF WEIGHT LOSS DATA AND FLUID INTAKE AND OUTPUT

Method	Total Wt Loss Kgms Body Wt + Water Intake − Fluid Output			Actual Wt Loss in Kgms During Treatment			Average *Fluid* Intake cc	Average *Fluid* Output cc
	Wt. Loss	σ	2σ diff	Wt Loss	σ	2σ diff		
External Heat	5 431	0 38		1 868	0 206		3836	190
Internal Heat	3 879	0 43		2 01	0 27		1490	89
Wt Diff Kgms.	*1 552*		*1 156*	0 142		*0 68*	*2346* (157%)	*101* (112%)

of the blood plasma ranging from 10 to 32 per cent in spite of a large fluid intake by mouth.

Approximately 66 per cent of the body weight is water. In a person weighing 70 kilos, the water is distributed approximately as follows: in the plasma, 3 kilos, in the lymph vessels and tissue spaces, 14 kilos; in the cells, 26 kilos. When water is lost, that in the tissue spaces is probably called on to conserve the plasma volume If that is true, then when the plasma volume is decreased, the water in the tissue spaces, which bathes the cells, is decreased To what extent the cells themselves become dehydrated is unknown

Gibson and Kopp[10] published a comparative study on total blood

[9] Kopp, I, and Solomon, H C Shock Syndrome in Therapeutic Fever Arch. Int. Med 60 597 1937

[10] Gibson, J G, and Kopp, I Studies in the Physiology of Artificial Fever I Changes in the Blood Volume and Water Balance. J Clin Invest 17 219 1938

and plasma volumes while using the Hypertherm, diathermy and radiant heat cabinets These data give further confirmation that low environmental temperatures produce less change in the blood volume than do high external temperatures It is unfortunate that these investigators, in our opinion, used the most unsatisfactory diathermy application suggested to raise body temperature—namely, the belt and cuff technique This method is liable to produce vascular collapse A cuff electrode was placed around the waist, one around each thigh, and one around each lower leg The thigh electrodes were connected to one terminal of the diathermy generator, and the calf and abdominal electrodes to the other The current flow was in series with the largest blood vessels in the abdomen and legs, and the resulting excessive heating of this region possibly tended to cause splanchnic dilatation However, although applied in this manner, diathermy produced less change in blood volume than those methods employing high environmental temperatures, even during the induction period when excessive heating of the splanchnic region would occur

Pijoan[11] reported that if the environmental temperature is low, and the alkalosis mild, the hematocrit change is minimal and within seven per cent of the original value Theoretically, the degree of change in the hematocrit value occurring during fever closely parallels the degree of tissue dehydration, because the blood tends to maintain its composition under all conditions

During hyperpyrexia, absorption of fluid from the gastrointestinal tract appears to be either delayed or impaired regardless of the method used for producing the fever, but it appears to be much more marked when external heat is used If fluids are given without regard to this physiologic disturbance, vomiting and nausea are very likely to result because of marked distention of the stomach Hartmann and Major,[12] experimenting on dogs

[11] Pijoan M Certain Biologic Effects During Artificial Fever Arch Phys Therapy 20 170 1939

[12] Hartmann F W and Major R C Pathological Changes Resulting From Accurately Controlled Artificial Fever Abst Am Int Fever Conf New York City, Paul B Hoeber Inc 1937

and using a Hypertherm, found that unless their animals were given repeated intravenous infusions of dextrose and saline solution, they did not survive the treatment.

The permeability of the lymphatic capillaries has been found by Hudack and McMaster[13] to be increased when the temperature of the part is raised. The edema of the hands, rather frequently seen after hyperpyrexia, is indicative of the altered capillary permeability.

McCarrell[14] studied the effect of hyperthermia as well as hypothermia on the cervical lymph flow of dogs and cats He believed the rise in cervical lymph flow which occurred as the result of fever was due to an accelerated rate of capillary filtration, brought about first by arteriolar dilatation, which increases the capillary pressure, and secondly by capillary dilatation, which enlarges the area available for filtration This shift of capillary fluid, which leads to a greater flow of more dilute lymph, the author believes, may be the causative factor of the common summer experience of swollen hands and feet

Krogh[15] has shown that agents which cause capillary dilatation will also cause edema or stasis, or both, when applied in sufficient intensity. High external temperatures, it would seem, might be an ideal dilator of the capillaries, at least in the skin. Gibson and Kopp[16] state that the loss of 5 cc. of tissue fluid per hour per kilogram of body weight is the limit of safety

It should be pointed out that changes in environmental temperature and humidity cause activity of the autonomic nervous system, which makes adjustments to meet such changes. But

[13] Hudack, S S, and McMaster, P D. Normal and Pathological Permeability of the Lymphatic Capillaries in Human Skin Soc Exp Biol & Med 29 944 1932

[14] McCarrell, J D: The Effect of Hyperthermia and Hypothermia on Cervical Lymph Flow Am J Physiol 130 34 1940

[15] Krogh, A · The Anatomy and Physiology of Capillaries, New Haven, Yale University Press, 1924

[16] Gibson, J. G, and Kopp, I · Studies in the Physiology of Artificial Fever I. Changes in the Blood Volume and Water Balance, J Clin Invest 17 219 1938

when environmental changes are too great or too sudden, the autonomic nervous system may be incapable of bringing about the necessary compensating changes Kopp and Solomon[17] state that "shock phenomena occurred only when the patients were in the Hypertherm, where the wet bulb temperature approximates 135° F., and never in the diathermy carbon lamp machine, where it is about 105° F."

In view of the foregoing, it is readily understood why the group in Osborne's series[18] subjected to external heat required 157 per cent more fluids than did the diathermy group. It would seem that when using external heat as the means of elevating body temperature, the physiological mechanism of the body is making a desperate effort to maintain adequate blood volume levels. With relatively high external temperatures—which are necessary if the temperature of the body is to be elevated by external heat alone—the superficial capillaries and veins will be markedly dilated. Much of the blood will consequently be contained in these dilated superficial vessels with resulting paucity of blood in the arteries Under such circumstances the heart will be laboring with marked effort to maintain an adequate circulation The decreased blood volume leads to decreased venous return flow and causes the heart to beat faster in order to keep the minute volume sufficient to carry on the circulation With reduced circulating blood volume and concentration of the blood, diastolic filling is profoundly disturbed

In addition to the foregoing, increase in capillary permeability, due to the effect of heat *per se*, and such anoxemia as may be induced by reduced blood volume, might cause a still further reduction in blood volume. Thus a vicious cycle would be established

The Effect of Skin Temperature on Heart Rate It is well known that a change in body temperature will increase the

[17] Kopp, I, and Solomon, H C Shock Syndrome in Therapeutic Fever, Arch Int Med 60 597 1937

[18] Osborne, S L Physiology of Hyperpyrexia, Dissertation for Doctorate, Northwestern University, Evanston, 1942

pulse rate Hill and Flack,[19] with patients lying in a hot water bath 105° to 110° F., observed a mean increase of forty-four beats per minute for a rise in rectal temperature of 2 4° C Bazett[20] in 1924 reported an increase, under similar conditions of thirty-seven beats per minute for a temperature rise of 2 0° C In the same year, Adolph and Fulton[21] exposed subjects in a room to an air temperature of 39 5° to 40 7° C The relative humidity of the air was 100 per cent The air was not in motion They concluded that the change in pulse rate was more closely related to surface than to deep temperature Grollman[22] in 1930 subjected individuals to air temperatures varying from 0° C to 45° C, but with relative low humidity, for periods of an hour He found that pulse rate was increased as the temperature was elevated Benson[23] in 1934 showed that the heart rate varies directly with the temperatures applied to the skin, and that by cooling the skin surface, even with a rising rectal temperature, the pulse rate would drop markedly Schmitt, Holmquest, and Marshall in 1936[24] published a composite rectal temperature and pulse rate curve taken from a series of eight patients treated by means of an air-conditioned cabinet combined with an Inductotherm Fig 228 The air temperature within the cabinet ranged from an initial temperature of 110° F during the induction period to 100° F during maintenance A high relative humidity was employed They plotted both median and maximum values The maximum rectal temperature curve ranged from 106° to 106 6° F for six hours,

[19] Hill, L , and Flack, M The Influence of Hot Baths on Pulse Frequency Blood Pressure, Body Temperature, Breathing Volume, and Alveolar Tensions in Man, J Physiol 38 57 1909

[20] *Bazett, H C Studies on Effects of Baths on Man, Am J Physiol* 70 412 1924

[21] *Adolph, E F , and Fulton, W B Effect of Heat on Circulation in Man,* Am J Physiol 67 574 1924

[22] *Grollman A Physiological Variations of the Cardiac Output in Man,* Am J Physiol 95 263 1930

[23] Benson, S Relative Influence of External and Body Temperature Upon the Heart, Arch Phy Therap 15 303 1934

[24] Schmitt, M G , Holmquest, H J , and Marshall, J G Fever Therapy, Physiotherapy Rev 16 93 1936

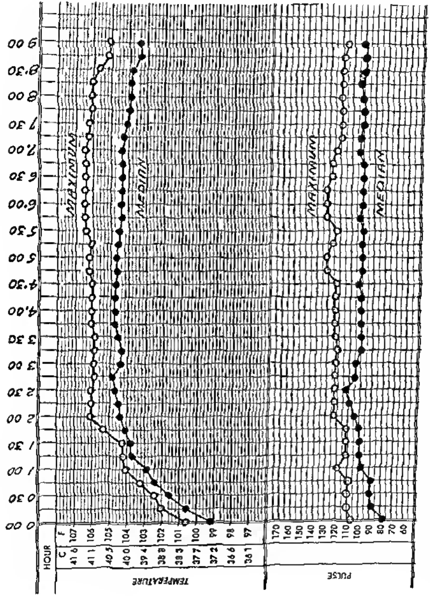

Fig 228 Maximum and median rectal temperatures and pulse rate

while the median rectal temperature was between 104° and 105° F. The pulse rate reached a maximum of 132 beats per minute, but only once during the entire curve; whereas the median pulse rate was approximately 100 beats per minute throughout the treatment.

A comparative study of the effects of high and low environmental temperatures on the pulse rate during artificial fever was published by Neymann in 1938 [25] A composite curve was presented showing the mean pulse rate and mean rectal temperature of two groups of patients; one group treated in the Kettering Hypertherm was exposed to high environmental air temperatures (120° to 160° F.), the relative humidity of the air being approximately 30 to 40 per cent; the other group was subjected to a relatively very low environmental temperature and a high relative humidity, approaching saturation In the latter group, electromagnetic induction was used as the heating agent and a treatment bag for minimizing heat loss from the patient The temperature and the relative humidity of the environmental air, in the case of the treatment bag, were dependent on heat transfer from the patient and on evaporation of perspiration, respectively Obviously the temperature would be relatively low, never exceeding that of the skin, and the humidity very high because of the small volume of still air to be humidified The fever curves were almost identical, but the pulse rate for the low environmental temperature associated with induction heating was decidedly lower than that for the high environmental temperature. This was not due to the particular apparatus which was employed, for Cook[26] in 1939 using a Kettering Hypertherm, but modified to operate at low temperature and high humidity, found that pulse rates remain moderate even during the induction of fever. Phillips[27] in 1938 demonstrated by an ingenious method, that on the same subject a high skin temperature produces a high pulse rate regardless of

[25] Neymann, C. A : Artificial Fever Charles C Thomas, Springfield, Ill, 1938

[26] Cook, M M . A Low Temperature Technic for Artificial Fever Induction Arch Phys. Therapy 20 544 1939

[27] Phillips, K. Physical Methods of Fever Production from a Physiologic Viewpoint Arch Phys Therap 19 473 1938

at 102 1° F, the difference in pulse rate between the two methods was statistically significant Table 63

The average pulse rate during the fever plateau was approximately 20 beats per minute greater with external than with internal heating Moreover, there seemed to be a greater tendency for the pulse rate and the temperature curves to fluctuate when external methods, employing high environmental temperatures, were used

Simpson[30] states there is no evidence of essential difference in pulse rate or other physiologic responses to fever induced by

TABLE 63

AVERAGE RECTAL TEMPERATURES AND AVERAGE CORRESPONDING PULSE RATES FOR EXTERNAL AND INTERNAL HEATING METHODS (15 SUBJECTS IN EACH GROUP)

Average Rectal Temperature		Average Pulse Rate		Difference in Pulse Rate		2σ difference
External	Internal	External	Internal	External	Internal	
102 1	101 6	115	109	+6		+7 2
102 9	103 3	128	109	+19*		+6 88
103 5	103 8	130	113	+17*		+6 6
104 4	104 3	139	113	+26*		+7 26

* Significant

either air conditioned external heat or so called internal heat methods With this we do not agree Simpson states he found an average increase of 7 beats per minute for each degree of temperature rise Looney and Borkovic,[31] using statistical methods of analysis, found that as the temperature of their patients was elevated, the mean pulse rate increased from 73 9 to 112 1 and finally to 116 3 The rate, they state, showed a significant positive correlation with temperature with an "r" of 0 709 and a probability of such a relationship occurring by chance of less than 1 in

[30] Simpson W H Studies on the Physiology of Fever J A M A 106 246 1936

[31] Looney J M and Borkovic E J The Changes Produced on the Oxygen and Carbon Dioxide Content of Arterial and Venous Blood of the Brain During Diathermy Therapy for General Paresis Am J Physiol 136 177 1942

100. They found a change of 5 1 beats per degree F., and even holding the temperature at the level of 105-106.6 for three to four hours caused no significant difference in the result.

Adolph and Fulton[32] believe that vasomotor sensory impulses may be set up in the peripheral vessels, which reflexly stimulate the accelerator mechanism of the heart They state that there is a direct correlation between superficial body temperature and heart rate, and that the three primary responses to high temperature, namely, gradual peripheral vasodilatation, acapnia, and loss of CO_2, are initiated by temperature conditions in the skin, and not by those in the central organs.

Benson[33] attributed the pulse rate acceleration to reflex action, probably initiated through the stimulation of the nerve endings in the skin with a subsequent chain of reflexes which terminate in the cardiac accelerator or depressor mechanism It is also interesting to note that he states artificial fevers may be produced, theoretically at least, without increasing the heart rate to any great extent The pulse curve published by Schmitt, Holmquest, and Marshall[34] would seem to substantiate this hypothesis

However, as already pointed out in the discussion on water balance, the increased pulse rate may be due to the heart working faster in an endeavor to keep the circulation at an adequate level Because of an actual decrease in blood volume during artificial fever, and of a relative diminution in venous return due to the marked dilation of the vessels of the skin resulting from high external temperature, the heart rate must be accelerated in order that an adequate circulation be maintained It is evident, regardless of the mechanism involved, that a low environmental temperature involves less risk for the patient than a high environmental temperature, insofar as circulatory embarrassment is concerned

[32] Adolph, E F, and Fulton, W B Effect of Heat on Circulation in Man, Am J Physiol 67 574 1924

[33] Benson, S Relative Influence of External and Body Temperature Upon the Heart Arch Phys Therap 15 303 1934

[34] Schmitt M G, Holmquest, H J, and Marshall, J G Fever Therapy Physiotherap Rev 16 93 1936

General Discussion of the Effects of the Two Methods of Producing Artificial Fever. The differences observed when using the two methods of producing artificial fever, are summarized and briefly discussed in the following:

A high skin temperature, as is produced by high environmental temperatures, does not directly paralyze the sweat glands But an indirect paralysis may possibly occur because of a central failure of the sweat centers, or to a peripheral effect of a change in the composition of the blood, or possibly to some substance liberated and carried by the blood. An indirect failure of the sweat glands apparently occurs in collapse or heat stroke

Fever produced by high external temperatures causes a reversal of the normal heat gradients of the body during the induction period of fever. After the fever plateau has been reached, the normal temperature gradients return It is probable that the greater discomfort reported by the patient when fever is induced by a high external temperature, is due to the high skin temperature and the reversal of normal heat gradients This view is in agreement with Cook,[35] who believes that the patient's discomfort is in direct proportion to the skin temperature, and consequently that there is less need for sedatives when low environmental temperatures are used

The greater dehydration, hemoconcentration, and acapnia associated with fever induced by high environmental temperatures, correlates well with the greater increase in pulse rate that occurs when such temperatures are used However, as pointed out previously, the increased pulse rate associated with external heating, is not entirely due to a decrease in blood volume

The observations made by Osborne, and those reported in the literature, constitute strong presumptive evidence that the use of high environmental temperature to produce fever is potentially more hazardous than the use of internal heating or Inductopyrexia. It should be made clear, however, that when proper precautions are taken in the selection and treatment of patients, the

[35] Cook, M M A Low Temperature Technic for Artificial Fever Induction Arch Phys Therap 20 544 1939

external heating method of inducing artificial fever may be used In fact, proper precautions must always be taken regardless of the method employed However, for the reasons presented in the foregoing discussions we prefer, and use a combination of the two methods induction heating to elevate the temperature and a low environmental temperature with high humidity to minimize heat loss

II Temperature Measurements of Various Organs and Tissues During Hyperpyrexia For many years a temperature of 98 6° F or thereabouts as registered by rectal or oral thermometers was assumed to be the average temperature of the body tissues Today this view is no longer held A subject, lightly clothed in a room at a temperature of 77° F will have an average skin surface temperature of approximately 92° F While the temperature of the feet may be as low as 70° F the abdominal surface may be as high as 95° F Benedict and Slack[36] in 1910 found that a constant temperature in the vagina and rectum was not attained until a depth of five to seven centimeters was reached They also showed that a rise or fall of the rectal temperature was accompanied by a corresponding change in the temperature of other parts of the body, such as the axilla and the groin In 1927 Bazett and McGlone[37] reported that a uniform temperature in the forearm and thigh was not attained until a depth of 2 5 cms was reached Burton[38] states that the true temperature of the interior of the body is not reached before a depth of several centimeters, and that this temperature is 4° to 5° F higher than the surface temperature He calculated that about fifty per cent of the body was within an inch of the surface He concluded that for scientific purposes the measurement of the surface temperature was equally if not more, important than the rectal temperature in the calcula

[36] Benedict F G and Slack E P A Comparative Study of Temperature Fluctuations in Different Parts of the Human Body Carnegie Institute of Washington 155 36 1910

[37] Bazett H C and McGlone B Physiological Responses to Heat Physiol Rev 7 531 1927

[38] Burton A C Human Calorimetry The Average Temperature of the Tissues of the Body J Nutrition 9 261 1935

tion of the average body temperature. However, rectal temperature is the only practical and safe clinical guide when administering fever therapy.

Measurements of the intragastric temperature were made by Thiessen[39] during artificial fever, for a mean elevation of oral temperature of 0 6° C The mean elevation of the rectal temperature was 0.7° C, and that of the intragastric temperature 1.2° C. Unfortunately, his article does not state whether externally applied or internally generated heat was employed for elevating the temperature It is conceivable, too, that with the use of high frequency energy for elevating the temperature, the technic employed with respect to the region in which maximum heat was being produced would have a bearing on the relative temperature elevations of different regions This would be particularly true for small temperature increases, obtained in relatively short times, before opportunity had been afforded for stabilization of temperature throughout the body.

The literature shows few temperature measurements other than oral, rectal, and axillary taken during hyperpyrexia Bierman[40] shows a single temperature curve in which he plots both the rectal and vaginal temperature However, the vaginal temperature was taken while a localized application of diathermy was made to the vagina during a hyperpyrexia treatment Neymann and Osborne[41] in 1934 published several temperature graphs, taken during artificial fever, which included the rectal, axillary, and subcutaneous temperatures of the abdomen, forearm, lower leg, thigh, Hunter's canal, liver, cisterna magna, and lumbar spine. Kendall, Webb, and Simpson[42] in 1936, in addition to measuring rectal temperatures, recorded the temperatures of the knee joint and of the posterior and anterior urethra, during a

[39] Thiessen, N W The Variations of Intragastric Temperature in Response to Vasodilating Agents Proc Staff Meet Mayo Clinic 8 22 1933

[40] Bierman, W Radiotherapy Arch. Phys Therapy 13 389 1932

[41] Neymann, C A, and Osborne, S L. The Physiology of Electropyrexia Am J Syph & Neurol. 18 28 1934

[42] Kendall, W. H., Webb, W, and Simpson, W M Artificial Fever Therapy of Gonorrheal Arthritis Am. J Surg 29 428 1935

hyperpyrexia treatment. In 1936 Culler and Simpson[43] published a temperature curve of a fever treatment using the external heating method The temperature of the orbit of the eye and that of the blood in the median antibrachial vein, as well as the rectal temperature, were recorded They reported that their values for deep temperatures obtained by external heating were essentially similar to those found during fever induced by high frequency currents They also stated they made temperature measurements in Hunter's canal, the rectosigmoid junction, the cervi uteri, the urinary bladder, and the stomach, but unfortunately no data or curves were presented They found that the temperature of the blood rose slightly faster than that of the other tissues during the induction of the fever, but all temperatures reached practically the same level as that of the rectum at the end of the first hour, and remained at approximately the same level during the five hours or more of fever maintenance

In 1930 Neymann and Osborne[44] became interested in the possibilities of artificial fever as a means of treating syphilis Bessemans and his collaborators,[45] working with rabbits as well as with man, demonstrated that a temperature of 42° C maintained for one hour, or a temperature of 40° C maintained for two hours, was capable of destroying the treponema pallidum *in vivo*.

In the United States, Carpenter and Boak in 1930[46] showed that, with adequate fever treatment, rabbits infected intratesticularly with treponema pallidum failed to develop chancres The temperatures were elevated 3 to 6° F. above the initial tempera-

[43] Culler, A. M , and Simpson, Walter M Artificial Fever in Cases of Ocular Syphilis Arch Ophthal 15 624 1936

[44] Neymann, C A , and Osborne, S L The Physiology of Electropyrexia. Am. J Syph & Neurol 18 28 1934

[45] Bessemans, J F A Albert The Local Application of Heat as an Adjunct in the Social and Individual Prophylaxis of Syphilis The Role of Tissue Temperature in the Pathogenesis and the General Pyretotherapy of Syphilitic Infection Urologic & Cutaneous Review 34 71 1930

[46] Carpenter, C M , and Boak, R. A The Effect of Heat Produced by an Ultra High Frequency Oscillator on Experimental Syphilis in Rabbits Am. J Syph 14 346 1930

ture, and maintained for periods of 30 to 50 minutes They used the *Radiotherm* devised by Whitney and Page, utilizing the high frequency electric field for producing the fever

In 1932 Boak, Carpenter, and Warren[47] presented further evidence in support of the value of fever in the treatment of syphilis by the determination of the thermal death time of the treponema pallidum *in vitro* The temperature and the time the temperature must be maintained to destroy the organism *in vitro,* which these investigators found, are within the limits of human tolerance. From a consideration of the work of these investigators, Neymann and Osborne recognized that for fever to be successful in the treatment of syphilis in the human being, it would be necessary to have all the tissues of the body at the thermal death temperature for the requisite period of time Hence they made measurements during the course of many fever treatments, in as many parts of the body as possible, in order to devise a technic of application that would assure adequate temperature of all tissues.

In some instances the patient's temperature was raised with external heat, in others by high frequency current, and in still others by a combination of both methods By the combined methods, they sought to overcome the temperature gradient between skin surface and internal tissues Effort was made to have all of the tissues exceed the thermal death temperature of the treponema pallidum—namely 105 8° F for at least 2 hours, or 107.6° F. for one hour.

The oral temperature was taken by means of the usual clinical thermometer. Rectal and axillary temperatures were recorded by means of electric recording thermometers Temperature readings of other tissues were made by means of thermocouples Temperatures were recorded every fifteen minutes Liver temperatures were taken by plunging the hypodermic thermocouple through the intercostal tissues into the liver Anterior urethral tempera-

[47] Boak R. A, Carpenter, C M, and Warren, S. L. Studies on the Physiological Effects of Fever Temperatures The Thermal Death Time of Treponema Pallidum in Vitro with Special Reference to Fever Temperatures J Exp Med 56 741 1932

tures were taken by passing a thermocouple, made from a urethral catheter, into the urethra A thermocouple was inserted in the region of Hunter's canal to secure temperatures in the depths of the thigh. The superficial temperatures of the cheek, neck, skin, thigh, forearm, forehead, and groin were made by inserting the couple into the subcutaneous layers of these areas.

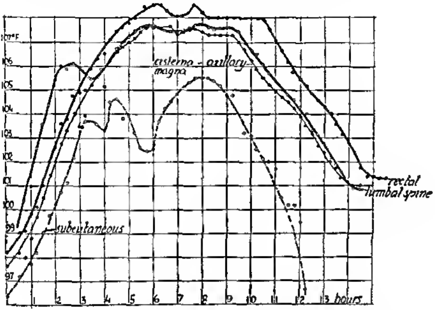

FIG 231 Complete temperature record of an individual patient (From Neymann and Osborne Am J Syph. and Neur 18 28 1934)

Table 64 summarizes the average temperatures of the various regions The temperature of the various regions was recorded for approximately each degree change in rectal temperature Each temperature recorded in the table was the average of the number of observations made The more difficult and dangerous regions to study were measured less frequently than the more accessible regions

Figure 231 gives the complete temperature record of an individual patient The rectal temperature was maintained at 108° F., or above, four hours. For one half hour of this period, the rectal temperature was maintained at 108 5° F. The subcutaneous tem-

TABLE 64

COMPARATIVE AVERAGE BODY TEMPERATURES DURING HYPERPYREXIA

Rectum	Oral	Lumbar Spine	Cisterna Magna	Liver	Thigh Muscles Deep	Ant. Urethra	Subcut Groin	Fore-head	Ext Cheek	Subcut. Neck	Axil	Subcut Fore arm	Subcut. Thigh	Skin
98.5	98.4	100.2	98.4	98.2	97.6	95.1	97.4	95.6	97.8	97.1	97.6	—	96.0	92.2
99.3	99.1	100.2	98.0	99.4	99.4	99.0	99.1	96.8	99.1	98.2	98.0	97.7	98.6	95.3
100.3	99.5	102.6	99.0	100.1	100.5	99.3	97.9	97.7	100.3	99.4	99.7	99.9	99.3	98.0
101.4	100.8	103.6	100.0	100.9	101.3	100.9	101.9	99.4	101.2	100.5	100.5	101.3	99.9	100.4
102.4	101.6	104.4	100.9	102.1	102.5	102.9	101.0	100.9	101.6	101.4	101.4	101.7	100.7	101.7
103.3	102.7	106.0	102.6	103.6	103.2	103.3	103.8	101.4	102.9	102.6	102.8	102.6	102.1	103.1
104.3	103.2	106.1	103.1	104.8	104.4	103.3	104.3	101.9	103.8	103.5	104.0	103.6	103.1	105.4
105.2	104.9	105.5	104.8	106.4	106.4	105.3	104.9	103.2	104.4	104.3	105.2	104.2	104.4	105.2
106.3	105.4	105.5	104.6	106.8	106.5	105.5	105.5	103.5	105.2	105.1	104.7	104.9	104.8	105.5
107.3	106.2	106.3	106.5	107.8	106.8	105.1	105.8	105.1	106.2	—	106.3	105.8	104.5	106.2
108.3	106.5	107.7	107.7	—	—	105.9	106.5	—	105.7	—	107.6	—	—	105.6
*26	6	1	1	2	6	4	2	2	4	3	6	2	4	8*

* Number of observations

perature was lowest thrnughout the induction and the maintenance of the fever, averaging one to three degrees Fahrenheit helow the rectal temperature. Similar results were ohtained in the rest of the series of patients when internal heating was employed as the method of producing fever.

Tahle 64 shows how widely the temperature of various parts nf the hody varies under resting conditions hefore the application of heat. Moreover, in spite of the application of heat sufficient in amount to elevate the rectal temperature of the patient several degrees, the temprature gradients were not completely ohliterated. Although uniformity of temperature of the various tissues was not realized, the difference in temperature became less pronounced. After the rectal temperature of 103.3 F. had been reached, the temperature of the liver exceeded that of all other regions. The temperature of the deep muscles of the thigh, however, approached closely that of the liver. For a while the temperature of the cisterna magna lagged somewhat behind that of the lumbar spine, but finally reached equilihrium with it. The oral temperature was lower than the rectal temperature, hut as already pointed out, *oral* temperatures are unreliable once a high temperature is reached. The subcutaneous temperatures were lowest; this is what was to he expected since internal heat was used to induce the fever. The anterior urethral temperature, according to Osborne,[43] exhihited a rather interesting cycle. The temperature would gradually rise to a peak temperature and then quickly return to a lower level. This was repeated often and appeared to bave a definite perindicity. Initially the anterior urethral temperature was next to the lnwest nf those measured. The suhcutaneous temperature of the fnrearm lagged hehind the majority nf the tissue temperature measurements.

In Fig. 232 the skin and axillary temperatures are plotted against the rectal temperature, which is used as a reference temperature. In this way, the relationship hetween the various body temperatures is far mnre easily recognized than in the usual

[43] Osborne, S L : Physiology of Hyperpyrexia, Dissertation for Doctorate, Northwestern University, Evanston, 1940

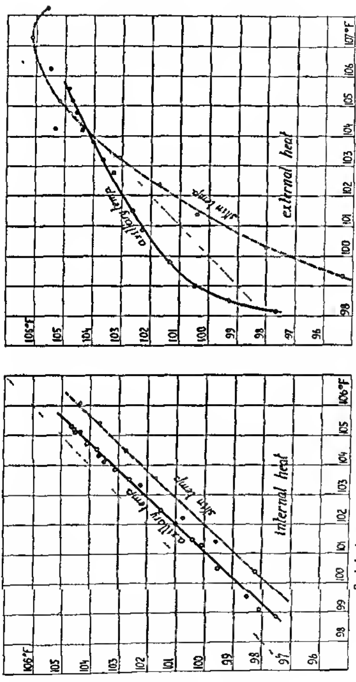

FIG 232 Axillary and skin temperature as a function of rectal temperature for internal and external heat Dotted line represents rectal temperature

found that the initial metabolic rates obtained on each patient before the start of fever therapy, on each treatment day, fluctuated from 15 to 35 per cent. He also reported that four of the seven patients showed greater variations than the usually accepted 10 per cent. He attributed this to the restricted early morning meal which his patients received Neymann and Osborne state their patients received no food. The question arises whether, in spite of their precautions, their patients were in a basal condition, or whether the basal metabolic rate of the general paretic might not differ from that of the normal individual.

Kopp found an increase in the basal metabolism of his patients of 7 to 14 per cent for each degree Fahrenheit rise of body temperature. The patients studied by Neymann and Osborne showed an average of 7 per cent per degree Fahrenheit rise of body temperature Du Bois[56] found a similar increase for his patients with an infectious fever. He called attention to the fact that the increase of metabolism with increased temperatures follows Van Hoff's Law He states that for ordinary temperatures this law can be expressed as follows: "With a rise of temperature of 10° C., the velocity of chemical reactions increases between 2 and 3 times. In other words, the coefficient is between 2 and 3." He further states that for practically all of the fever experiments the coefficient is within these limits, the average being 2 3.

The coefficient referred to is the ratio of the velocity constant at the higher temperature to that at the lower temperature. This coefficient is represented by the letter Q. If the difference in temperature is 10° C, the coefficient is written Q_{10}.*

[56] DuBois, E F Metabolism in Fever, J A M A 77 352 1921

* *Effect of Temperature on Reaction Velocity* Arrhenius showed that the rate of change of the natural logarithm of the velocity constant of a chemical reaction with respect to temperature is inversely proportional to the square of the absolute temperature Expressed in the form of a differential equation $d/dT\ (\log_e K) = E/R \cdot 1/T^2$; in which K is the velocity constant at the absolute temperature T, R is the gas constant, and E a constant. *If we let C,* a constant, represent E/R, we have

$$d\ (\log_e K) = C/T^2\, dT$$

Integrating this equation,

$$\log_e K = -C/T + A, \text{ in which A is a constant of integration}$$

$$\text{If } T = T_1, K = K_1; \text{ and if } T = T_2, K = K_2$$

temperature (dotted line, Fig 232) rises more rapidly than do the skin or axillary temperatures The total absence of parallelism between the various temperature curves indicates that marked disruption of the normal temperature gradients results during fever produced by external heat Even though the disruption may obtain during the induction period only, it must be kept in mind that this period is of great importance and that the reaction of the patient during this time may determine whether or not the treatment can be carried to a successful conclusion

III THE EFFECT OF HYPERPYREXIA ON BASAL METABOLISM The studies of Burton,[49] Kopp,[50] Neymann and Osborne,[51] and Osborne[52] are the only reports on the effect of artificial fever on the basal metabolic rate of patients while undergoing treatment Nasset, Bishop, and Warren,[53] and Nasset[54] made a comprehensive study of basal metabolism in dogs while using high frequency current to raise body temperature

Osborne[55] reported there was an appreciable increase in the metabolic rate when a rectal temperature of 105° F was reached He reported an average increase in basal metabolism of 7 per cent for each degree of temperature rise through the range 98 6° F to 105° F In four of eleven determinations, basal rate exceeded the usual ± deviation of 10 to 15 per cent Repeated determinations made over several days might have shown these readings to be within the variability of these subjects Kopp

[49] Burton A C Human Calorimetry The Average Temperature of the Tissues of the Body J Nutrition 9 261 1935

[50] Kopp I Metabolic Rates in Therapeutic Fever Am J Med Sci 190 491 1935

[51] Neymann C A and Osborne S L The Physiology of Electropyrexia Am J Syph & Neurol 18 28 1934

[52] Osborne S L Physiology of Hyperpyrexia Dissertation for Doctorate Northwestern University Evanston 1940

[53] Nasset E S Bishop F W and Warren S L Physiological Effects of High Frequency Current Am J Physiol 96 1937

[54] Nasset E S Physiological Effects of High Frequency Current II Further Studies on Respiration Metabol sm of Anesthetized Dogs Am J Physiol 101 194 1932

[55] Osborne S L Physiology of Hyperpyrexia Dissertation for Doctorate Northwestern University Evanston 1940

found that the initial metabolic rates obtained on each patient before the start of fever therapy, on each treatment day, fluctuated from 15 to 35 per cent He also reported that four of the seven patients showed greater variations than the usually accepted 10 per cent. He attributed this to the restricted early morning meal which his patients received Neymann and Osborne state their patients received no food The question arises whether, in spite of their precautions, their patients were in a basal condition, or whether the basal metabolic rate of the general paretic might not differ from that of the normal individual.

Kopp found an increase in the basal metabolism of his patients of 7 to 14 per cent for each degree Fahrenheit rise of body temperature The patients studied by Neymann and Osborne showed an average of 7 per cent per degree Fahrenheit rise of body temperature Du Bois[36] found a similar increase for his patients with an infectious fever He called attention to the fact that the increase of metabolism with increased temperatures follows Van Hoff's Law He states that for ordinary temperatures this law can be expressed as follows: "With a rise of temperature of 10° C., the velocity of chemical reactions increases between 2 and 3 times In other words, the coefficient is between 2 and 3" He further states that for practically all of the fever experiments the coefficient is within these limits, the average being 2 3

The coefficient referred to is the ratio of the velocity constant at the higher temperature to that at the lower temperature This coefficient is represented by the letter Q If the difference in temperature is 10° C, the coefficient is written Q_{10} *

[36] DuBois, E F Metabolism in Fever, J.A.M.A. 77 352 1921

* *Effect of Temperature on Reaction Velocity* Arrhenius showed that the rate of change of the natural logarithm of the velocity constant of a chemical reaction with respect to temperature is inversely proportional to the square of the absolute temperature Expressed in the form of a differential equation $d/dT\,(\log.\ K) = E/R \cdot 1/T^2$, in which K is the velocity constant at the absolute temperature T, R is the gas constant, and E a constant. If we let C, a constant, represent E/R, we have

$$d\,(\log.\ K) = C/T^2\,dT$$

Integrating this equation,

$$\log.\ K = -C/T + A, \text{ in which A is a constant of integration}$$

If $T = T_1$, $K = K_1$; and if $T = T_2$, $K = K_2$.

Nasset,[57] producing artifical fever in dogs, was unable to obtain the Du Bois temperature coefficient (Q_{10}) of 2 3 when he substituted in the formula the data obtained from his experiments He used a $Q_{10} = 2\ 64$ in attempting to account for a portion of the heat production of their animals Similar values can be obtained from the data of others who used hot air or hot water to elevate the body temperature The results of McConnell, Yogloglou, and Fulton[58] show that on exposure to hot, humid air, the oxygen consumption was in many cases excessively high, giving some Q_{10} values as high as 49 2 Plaut and Willbrand[59] report

[57] Nasset, E S Physiological Effects of High Frequency Current II. Further Studies on Respiration Metabolism of Anesthetized Dogs, Am. J Physiol 101 194 1932

[58] McConnell, W J, Vogloglou C. P, and Fulton, W G Basal Metabolism Before and After Exposure to High Temperatures and Various Humidities Public Health Report, 39 3075 1925

[59] Plaut, R, and Willbrand, E Zur Physiologie des Schwitzens Zeitschr f Biol 74 191 1922

Then

$$\log_e K_2 = -C/T_2 + A, \text{ and } \log_e K_1 = -C/T_1 + A$$

From these we obtain

$$\log_e K_2 - \log_e K_1 = C\ (1/T_1 - 1/T_2)$$

or $\log_e K_2/K_1 = C\ (1/T_1 - 1/T_2)$

If $T_2 - T_1 = 10°$, the ratio K_2/K_1 is represented by Q_{10}. Then $\log_e Q_{10} = C\ 10/T_1 T_2$ From the preceding equation, we obtain for the constant C

$$C = [T_1T_2/(T_2 - T_1)] \log_e K_2/K_1$$

Substituting this value for C in the equation for $\log_e Q_{10}$ we obtain $\log_e Q_{10} = [10/(T_2 - T_1)] \log_e K_2/K_1$, or, changing to common logarithms,

$$\log_{10} Q_{10} = [10/(T_2 - T_1)]\ (\log_{10} K_2 - \log_{10} K_1)$$

Example Assuming for Q_{10} the value 2 3, compute Q_1, Q_2 Q_3 Q_4, etc to Q_{10}

Solution $\log K_2/K_1 = \log Q$

Then $\log Q_{10} = [10/(T_2 - T_1)] \log Q$

From this $\log Q = [(T_2 - T_1)/10] \log Q_{10}$

$= [(T_2 - T_1)/10] \log 2\ 3$

$= 3617\ (T_2 - T_1)/10$

$= 036\ (T_2 - T_1)$

Since $Q = K_2/K_1$ $K_2 = K_1 Q$ The increase in the velocity constant as temperature rises is $K_2 - K_1 = K_1 Q - K_1 = K_1 (Q - 1)$ The per cent increase is $[K_1 (Q - 1)/K_1] \times 100\% = Q - 1 \times 100\%$ Using this expression the

an experiment on a human subject from which a $Q_{10} = 13.4$ may be calculated Nasset concluded that increased pulmonary ventila

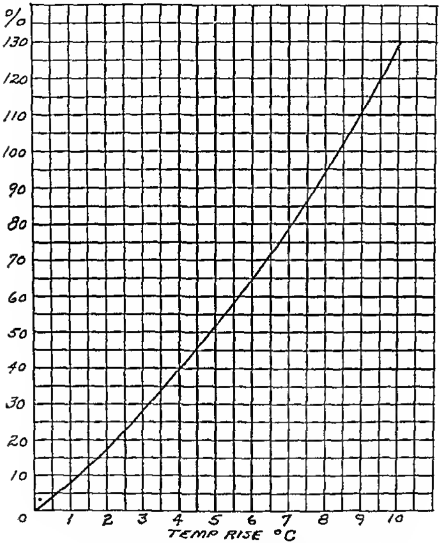

FIG 233 Per cent increase in velocity constant as a function of temperature rise in degrees centigrade

per cent increase in reaction velocity was calculated for various temperature increases and recorded in the following table

tion was probably the factor largely responsible for the high heat production in his experiments Kopp[60] expressed a similar view

Burton[61] states that the rectal temperature at no time represents the true average temperature of the body He is of the opinion that many of the contradictory results in this field are due to the inadequacy of the rectal temperature to represent the true average temperature of the active tissues Burton uses the following formula for obtaining the average body temperature Average temperature = 0 65 × rectal temperature + 0 35 × average sur face temperature

[60] Kopp I Metabolic Rates in Therapeutic Fever Am J Med Sci 190 491 1935

[61] Burton A. C Human Calorimetry The Average Temperature of the *Tissues of the Body J Nutrition 9 261 1935*

T −T	log Q	Q	Per Cent Increase in Reaction Velocity
0	0	1 00	0
1	036	1 086	8 6
2	072	1 180	18
3	108	1 282	28
4	144	1 393	39 3
5	18	1 514	51 4
6	216	1 644	64 4
7	252	1 786	78 6
8	288	1 941	94 1
9	324	2 109	110 9
10	36	2 3	130

In Fig 233 per cent increase in the velocity constant is plotted aga nst temperature rise in degrees centigrade. *It should be noted that the rate* of increase in the velocity of reaction does not increase linearly with tempera ture rise However in the range 0 to 3° C corresponding to 0 to 6° F approximately the curve is practically a straight line Therefore average in crease in metabolism as computed by Neymann and Osborne and others per degree rise during artificial fever is sufficiently close for all practical purposes According to the graph the average increase in reaction velocity per degree centigrade rise is 13 3 This is found by determining the area in terms of per cent degrees under the curve between the ordinates at 0 and 3 and dividing this value by the range of 3 degrees The average per cent increase in reaction velocity of 13 3 per degree centigrade corresponds approximately to 5/9 × 13 3 or 7 4 per degree Fahrenhe t. Neymann and Osborne s value of 7 per cent agrees well with this value of 7 4 per cent.

IV THE EFFECT OF HYPERPYREXIA ON THE ELECTROCARDIOGRAM The effect of byperpyrexia on the electrocardiogram has received very little attention Wiggers and Oreas[62] in 1932, however, reported some animal experimentation Neymann and Osborne[63] in 1931 reported a summary of an electrocardiographic study they made while treating patients with dementia paralytica hut details of the study were not provided Bishop Horton, and Warren[64] in 1932 stated that the electrocardiogram shows some changes, but that the interpretation is not clear The first, and so far as the literature shows, the only complete study of this important phase of hyperpyrexia appeared in 1936 This work was done by Vesell and Bierman[65] In 1936 Neymann, Blatt, and Osborne[66] published an electrocardiographic tracing of a patient before and after treatment for chorea, complicated with rheumatic carditis The electrocardiogram showed improvement after the treatments Osborne, Blatt and Neymann[67] in 1938 reported that artificial fever does not adversely affect the normal heart or the cardiovascular system Huddleston, Baldes and Krusen[68] reported a study of seven normal subjects and four patients on whom they recorded electrocardiograms and optical polygrams simultaneously at various intervals during byperpyrexia treatments

[62] Wiggers C J and Oreas O Circulation Changes During Hyperthermia Produced by Short Radio Waves (Radiothermia) Am. J Med Sci 100 614 1932

[63] Neymann C. A and Osborne S L The Treatment of Dementia Paralytica with Hyperpyrexia Produced by Diathermy J.A.M.A 96 7 1931

[64] Bishop F W Horton C B and Warren S L A Clinical Study of Artificial Hyperthermia Induced by High Frequency Current Am J Med Sci 184 515 1932

[65] Vesell H and Bierman W The Electrocardiogram in Fever Changes in Induced Hyperpyrexia Am. J Med Sci. 191 484 1936

[66] Neymann C. A Blatt M L and Osborne S L The Treatment of Chorea Minor by means of Electropyrexia J A M A. 107 938 1936

[67] Osborne S L. Blatt M L and Neymann C A. Electropyrexia in Rheumatic Carditis Chorea, and Certain Other Childhood Diseases Physioth Rev 18 68 1939

[68] Huddleston O L Baldes E J and Krusen F Studies on the Cardiac Activity of Human Subjects During Artificial Hyperpyrexia Proceed Am Physiol Soc 126 540 1939

In 1934 Maher and Osborne[69] made a study of the electrocardiographic changes occurring during and following hyperpyrexia, in an attempt to evaluate the effects and possible hazards of the treatment upon the heart. Their twelve patients showed a normal sinus mechanism before treatment, and this mechanism remained unchanged in all cases No arrhythmia was produced as a result of the high temperature Clinically, extrasystoles were not detected, nor were they recorded electrocardiographically In one case, paroxysmal auricular fibrillation occurred previous to treatment. The presence of the paroxysm was noted clinically, and verified after the electrocardiographic records were studied the following day. The first few records taken during the initial temperature rise showed the arrhythmia, but all records subsequent to a temperature of 102° F. were those of a normal sinus mechanism.

Chart I gives the complete cardiographic findings of this patient. Chart II, of another patient, is also presented because of the interesting change in axis deviation

CHART I

Record of Patient F. Age 64 years
Diagnosis
1. Chronic infectious arthritis
2. Cardiac Functional Class IIA

Anatomic Generalized Arteriosclerosis
Cardiac hypertrophy
Aortic sclerosis
Physiologic
Sinus mechanism
Auricular fibrillation
Electrocardiographic Findings
Disappearance of Auricular Fibrillation at a Rectal Temperature of 101 8° F.
Electrocardiogram No I was taken just prior to starting the fever

[69] Maher, C, and Osborne, S L Unpublished data.

therapy. It shows an auricular fibrillation with a rate of 150. The QRS complexes are slightly slurred in all leads. The T-waves are upright in Lead I and apparently diphasic in Leads II and III. The axis deviation is normal.

Electrocardiogram No. II was taken one hour after initiating fever therapy. Temperature was 100.3° F. The patient still had an auricular fibrillation with a rate of 170 The slurring of the QRS complexes was approximately the same. There was a slight tendency to right axis deviation. The T waves were of the same contour. There were four beats in Lead I which show a greater amount of slurring and notching than the other beats

Electrocardiogram No III was taken one hour and thirty minutes after the onset of the treatment. Temperature was 101° F. The fibrillation was still present, rate being 170 The voltage was approximately 50 per cent of the original. The slurring was the same and the contour of the T waves was unchanged

Electrocardiogram No. IV was taken two hours after the beginning of treatment. Temperature was 101.8° F The auricular fibrillation had disappeared and had been replaced by a normal sinus mechanism having a rate of 110. The T waves were upright in Lead I, blunted in Lead II, and flat in Lead III. The P-R interval was 0 20 seconds The slurring was about the same The voltage was about 50 per cent of the normal.

Electrocardiogram No. V was taken two hours and thirty minutes after the beginning of the treatment. Temperature was 103° F. The sinus mechanism was still present with a rate of 90. The curve was the same as Number IV.

Electrocardiogram No VI was taken at about two hours and forty minutes after the onset of treatment Temperature was 104° F. It was practically the same as No. V with a rate of 100

Electrocardiogram No. VII was taken three hours and fifteen minutes after the onset of the treatment The rate was 90. There was a mild right axis deviation. The T waves were changed in contour in Lead I with a slightly convex RT segment They were upright in Lead II and diphasic in Lead III The slurring of the QRS complexes was approximately the same.

Electrocardiogram No VIII was taken four hours after the beginning of treatment and one hour after treatment had been discontinued. There was a definite right axis deviation with lower voltage in Lead I.

The T waves were almost isoelectric in Lead I, blunted in Lead II, and blunted in Lead III. The slurring of the QRS complexes was the same.

Electrocardiogram No IX was taken five hours after the beginning of the treatment and two hours after discontinuance. It was practically the same as curve No. VIII.

Electrocardiogram No. X was taken about two hours and a half after treatment was discontinued It shows a normal axis deviation The P-R interval was 0.20 seconds The T waves were upright in Leads I and II, and blunted in Lead III. The voltage was approximately normal, and the slurring of the QRS complexes was about the same

Electrocardiogram No XI was taken seven hours after the discontinuance of treatment. It showed a normal axis deviation. The P-R interval was 0 20 seconds There was a slight slurring in the QRS complexes in all leads The T waves were upright in all leads

Summary: It would appear that this patient developed an auricular fibrillation before the treatment was started, and an emotional upset is the only factor to account for this The fibrillation disappeared when the temperature reached 102° F. and did not recur during this or subsequent treatments. There was a definite change in axis deviation. There were many changes in the T waves.

CHART II

Record of Patient D
Diagnosis:
Etiologic—syphilis
Anatomic—Aortitis
Physiologic—Sinus mechanism
Functional—Class IIA
Electrocardiogram No. I (Control)
Rate 100
Rhythm—Sinus mechanism
P-R Interval—0 19 seconds
QRS—Slurred near the base line in Lead II and slurred in the down stroke in Lead III.
T Waves—Upright in Leads I, II, and III with a slight elevation of the RT segment in Lead II.
Blood Pressure 98/64—Temp 99 4° F.

Electrocardiogram No II Shows no change whatsoever Blood Pressure 104/70 Temp 100 9° F

Electrocardiogram No III This curve showed about a 15 per cent decrease in the voltage Otherwise no change Temp 101 5° F Blood Pressure 110/88

Electrocardiogram No IV This curve showed the greatest decrease in voltage in Lead III Otherwise the curve remained practically the same Temp 102 6° F Blood Pressure 130/88

Electrocardiogram No V This was practically the same as curve No IV Temp 103 7° F Blood Pressure 126/80

Electrocardiogram No VI The same as No V Temp 104 5° F Blood Pressure 108/74

Electrocardiogram No VII This curve showed a slight blunting of the T waves in Leads I and II There was a suggestive change in Lead III of a Q wave Temp 104 4° F Blood Pressure 108/78

Electrocardiogram No VIII The voltage was decreased about 25 per cent There was still a very small Q wave in Lead III The voltage was quite low Temp 104 5° F Blood Pressure 108/74

Electrocardiogram No IX Same as No VIII Temp 104 5° F Blood Pressure 104/74

Electrocardiogram No X The same as No VIII and IX Temp 104 5° F Blood Pressure 104/74

Electrocardiogram No XI The voltage was decreased about 30 per cent, most marked in Lead III The T waves showed some blunting Temp 104 5° F Blood Pressure 108/74

Electrocardiogram No XII There was almost a 50 per cent decrease in the voltage Temp 101 5° F Blood Pressure 104/74

Electrocardiogram No XIII This curve showed a marked change in voltage Right axis deviation appeared with a diphasic complex in Lead I, small upright complex in Lead II, and an upright complex in Lead III which was higher than that of Lead II The T waves were upright but blunted There was a very small Q wave in Lead III and the voltage was higher Temp 101 1° F Blood Pressure 104/74

Electrocardiogram No XIV The right axis deviation was still present—otherwise no change Temp 98 6° F Blood Pressure 108/80 The electrocardiogram was taken 2 hours after return of normal temperature

Electrocardiogram No XV This curve showed a normal axis deviation and the curve was practically the same as that of the control. It was taken 4 hours after return of normal temperature

Electrocardiogram No XVI This was essentially the same as the control, except the voltage was somewhat less in Lead III It was taken the following morning, 26 hours after taking first, or control, electrocardiogram

Summary The outstanding change in this case was the change in the axis deviation There was a moderate change in voltage The T waves were slightly blunted There was a suggestive Q wave in Lead III

The conduction time from auricles to ventricles was normal in all twelve cases, namely, 0 16 to 0 20 seconds, and remained so throughout the entire period of treatment

The QRS complexes showed no change in time interval in any patient The time intervals were all within 0 10 second During the fever, the height of the QRS complexes progressively decreased The decrease seemed to be in direct proportion to the degree of perspiration The perspiration, it was thought, provided a low resistance path over the skin from one arm lead to the other, resulting in a lowered potential difference Therefore Maher and Osborne used surgical needles to replace the usual arm electrodes The needles were inserted just beneath the skin of the chest about four inches apart, one on each side of the sternum The leg electrode was applied in the usual way Because of the greater distance between this electrode and the chest electrode, leakage of current over the skin between the leg electrode and the other electrodes was negligible This evidently solved the problem, for all subsequent electrocardiograms failed to show the former progressive decrease in the amplitude of the QRS complexes

Regarding electrocardiographic changes during fever therapy Vesell and Bierman[70] state

The alterations of electrocardiographic waves were not uniform P and T waves were almost as frequently increased in size as decreased The R wave, however, most often became smaller and the P R and QRS intervals in most instances shortened The RT level was usually de

[70] Vesell H. and Bierman W The Electrocardiogram in Fever Changes in Induced Hyperpyrexia Am. J Med Sci 191 484 1936

pressed, never elevated Of special significance was the transformation of several normal amplitudes or intervals to abnormal ones as well as the reverse This involved particularly the R and T amplitudes Worthy of mention is the development of a prominent Q_3 in one instance

In conclusion these investigators state that "fever produced no harmful effects upon the heart"

According to Bishop, Horton, and Warren[71] electrocardiograms show the decrease in voltage of the action currents of the heart consistent with a low blood pressure Huddleston, Baldes, and Krusen[72] reported that the electrocardiograms showed a disappearance of sinus arrhythmia and a reduction of the conduction time or PR interval The findings of Maher and Osborne[73] are essentially in accord with these investigations, for they too observed no changes in the intrinsic physiology of the heart

V The Effect of Hyperpyrexia on the Blood and Circulation *Blood pH* Several reports have appeared on the effect of an elevation of body temperature on the pH of the blood Haggard[74] in 1920 experimenting on himself, found a distinct lowering of the CO_2 tension after twenty minutes in a very hot bath As no corresponding fall in the CO_2-combining power of the blood was found, be suggested that a change in the reaction of the blood had taken place This suggestion was verified by the direct measurements of Koehler[75] in 1923 He showed that the acid base equilibrium shifted toward the alkaline side not only during acute clinical fevers, but also during a "pure thermic fever" as he

[71] Bishop F W Horton C B and Warren S L A Clinical Study of Artificial Hyperthermia Induced by High Frequency Current Am J Med Sci 184 515 1932

[72] Huddleston O L Baldes E J and Krusen F Studies on the Cardiac Activity of Human Subjects During Artificial Hyperpyrexia Proc Am Physiol Soc 126 540 1939

[73] Maher C and Osborne S L Unpublished Data

[74] Haggard H W Hemato respiratory Functions The Alteration of the Carbon Dioxide in the Blood During Elevation of Body Temperature J Biol Chem 44 131 1920

[75] Koehler A B Acid base Equilibrium I Clinical Studies in Alkalosis Arch Int Med 31 590 1923

designated it He secured his 'thermic fever by immersing the subjects in a hot bath for a maximum period of thirty seven minutes The resulting oral temperature ranged from 103 2° F to 105 3° F, and the blood pH changed from a minimum of 7 365 to a maximum of 7 605 In the same year Cajori, Crouter, and Pemberton[76] studied the effect of heat on acid base balance They exposed fifteen subjects to the heat of an electric light cabinet, from which only the head protruded The subjects were exposed to the radiant heat for a period of forty to fifty minutes, but neither oral nor rectal temperatures were recorded The tempera ture of the skin reached 120° F to 130° F after twenty minutes The pH values at the height of the temperature ranged from 7 24 to 7 55, representing an increase ranging from 0 03 to 0 26 Other investigators have reported rises in pH of the blood associated with artificial fever, the final values of pH ranging from 7 43 to 7 7[77, 78, 79, 80, 81]

The observations just referred to were for the most part carried out on normal individuals In the majority of the cases the fever attained was not held for any appreciable period of time Osborne therefore thought it advisable to study pH changes of the blood of actual patients while undergoing fever therapy[82]

Thirty three experiments were performed using the Dole glass electrode and Coleman Potentiometer Table 65 gives a complete

[76] Cajori F A Crouter C Y and Pemberton R Effects of Heat on Acid base Balance J Biol Chem 57 217 1923

[77] Bischoff F Long M L and Hill E Acid Base Equ librium in Hyper thermia Induced by Short Radio Waves J Biol Chem 90 321 1931

[78] Bischoff F Ullman H J Hill E and Long M L Stud es in Hyper thermia Induced by the High Frequency Electric Current J Biol Chem 85 675 1930

[79] Danielson W N and R M Stecher Acid Base Balance of Blood in Hyperthermia Proc Soc Exp Biol & Med 32 1015 1935

[80] Hopkins H Chemical Changes in the Blood Induced by Hyperpyrexial Baths Arch Neuro & Psych 31 597 1934

[81] Landis E M Long W H Dunn J W Jackson C L and Meyer W Studies on the Effects of Baths on Man Am J Physiol 76 35 1926

[82] Osborne S L. Physiology of Hyperpyrexia D ssertat on for the Doc torate Northwestern University Evanston 1940

summary of his data, and Table 66 gives a summary of observations made by various investigators.

It is apparent that artificial fever produces a significant elevation of the blood pH. The average pH value of 7 55 found at a temperature of 104° F. indicates a state of uncompensated alkalosis. Hartman[83] in discussing a paper by Lepore at the Fifth Annual Fever Conference, stated that he had determined the pH

TABLE 65

EFFECT OF HYPERPYREXIA ON BLOOD PH

	Minimum and Maximum	Average of 33 Determinations	2σ Diff	Increase over Control Period
Control Period	7 30–7 52	7 41	0 01	0
Temperature at 104° F	7 35–7 72	7 55	0 038	0 14
End of 4 hours at 104° F	7 30–7 83	7 52	0 0396	0 11
After Return to Initial Temperature	7 32–7 51	7 418	0 028	0 003

of the blood of twelve patients electrometrically and found a marked alkalosis in all of them The loss of carbon dioxide by the body through the lungs and sweat during the fever is undoubtedly largely responsible for increasing the alkalinity of the blood Through the skin, too, there is a carbon dioxide loss of some importance, as was previously discussed in Section Five. Koehler is of the opinion there is a direct correlation between cyanosis and certain types of alkalosis Mild cyanosis is not an uncommon occurrence in fever therapy. Koehler believes that fever alkalosis is due to increased lung ventilation and the rapid elimination of carbon dioxide from the blood, thus causing a carbon dioxide

[83] Hartman, F W Abstract & Papers & Discussion Fifth Annual Fever Conference, Dayton, Ohio, 1935

INVESTIGATORS ON EFFECT OF HYPERPYREXIA ON BLOOD pH

Investigators	Method Used for Elevating Body Temp	°T Body Temp	Minimum and Maximum Blood pH	Method of Determination
Koehler, 1923	Hot Water Bath 37 Minutes	Oral 103 2 105 3°	7 365 7 605	Hydrogen Electrode
Cajori Crouter, and Pemberton, 1923	Electric Light Cabinet 40–50 min	Not Given	7 24–7 55 Increased 0 32–0 26	Computed from CO_2 absorption curves Four by Colorimetric Method of Cullen
Land s Long Dunn Jackson and Meyer 1926	Hot Water Baths 2 Hours	39 2 to 40 4° C	7 56–7 74 Increased 0 12 0 33	Colorimetric Method of Cullen
Bischoff Ullman Hill & Long 1930	Conventional Diathermy 1½ 3½ Hrs	Oral 37 2–39 4° C	7 52–7 70 Mat Increased 0 23	Quimby Drove Electrode
Hopkins 1934	Hot Water Bath 30–45 min	105 106	7 43–7 55 Increased 0 02 0 16	Colorimetric Method of Hastings and Sendroy
Danielson and Stecher 1935	Kettering Hypertherm	104 2–4 hrs	Elevated—No Figures Given	Not Given
Osborne 1940	Inductotherm and Cabinet	104 Rectal Maintained 4 hours	*Averages* 7 55 at 104 7 57 after 4 hrs Maintenance Increased 0 14–0 11	Coleman Potentiometer and Dole Glass Electrode

deficit, which in turn results in the passage of sodium ions into the tissue fluids and partially into the urine. Landis and his collaborators do not believe that hyperventilation is the sole cause of the pH change, but that it is dependent on several factors, such as the functioning of the kidneys, the degree of sweating, and the formation of lactic acid.

Bischoff, Ullmann, Hill, and Long[84] do not agree with Koehler that an anoxemia exists in the presence of a fever alkalosis. As a result of the lowered carbon dioxide tension in the blood and the increased pH, the stability of the oxyhemoglobin increases If the circulation and the metabolism did not increase concurrently, the question would be quite simple. With an increase in circulation, however, the tissues are exposed to more blood per unit of time so that the effect of the hemoglobin stability might be offset if the demand for more oxygen due to increased metabolism were not too great.

It would seem logical, as we have pointed out in Section Five, that if rebreathing is employed to counteract hyperventilation, failure of treatment due to hyperventilation may be prevented.

Specific Gravity of the Blood. Several investigations on the effect of fever on hemoconcentration have been made, chiefly on animals but a few on human beings; none, however, under comparable conditions. Observed blood changes[85] have frequently been explained as due to a concentration phenomena. According to Howell[86] the specific gravity of human blood may vary from 1.041 to 1.067, the average being 1.055. All of Osborne's determinations, Table 67, came within this range.[87] Gibson and Kopp[88]

[84] Bischoff, F, Ullmann, H J, Hill, E, and Long, M L: Studies in Hyperthermia Induced by the High Frequency Electric Current J Biol. Chem 85 675 1930

[85] Neymann, C A, and Osborne, S L The Treatment of Dementia Paralytica with Hyperpyrexia Produced by Diathermy J.A.M.A. 96.7.1931

[86] Howell, W H. Textbook of Physiology, Ed. 13 W. B Saunders Co, Philadelphia, 1943.

[87] Osborne, S L.: Hyperpyrexia and the Specific Gravity of Blood. Arch Phys. Therap 22 407·1941.

[88] Gibson, J G, and Kopp, I Studies in the Physiology of Artificial Fever Changes in the Blood Volume and Water Balance J Clin Invest 17 219 1938

state that one of the major physiologic effects of artificial fever induced by physical means is a diminution in circulating blood volume. They state that the degree of reduction in plasma volume is determined by the difference in rate of outflow from skin, lungs, and kidneys, and of effective absorption of fluids administered If insufficient fluids are given, the tissue fluids of the body are drawn upon for the maintenance of plasma volume; this results in dehydration Undoubtedly, the blood density will be dependent

TABLE 67

EFFECT OF HYPERPYREXIA ON THE SPECIFIC GRAVITY OF BLOOD

	Elapsed Time Hours	Average Value	2σ Difference ±	Change ± From Control	No of Observations
Initial (Control)	0	1 0536	—		30
104° F	2	1 0555	0 0018	0 0019	
104 6° F	6	1 0552	0 0018	0 0016	
Initial (Return to control level)	8	1 0544	0 002	0 0008	

upon the balance of fluid loss and fluid gain, and one might readily criticize Osborne's work in that he did not control these variables But he stated that fluids were given, as to quantity and rate, according to his judgment of the patient's need He was interested, primarily, in ascertaining changes in hemoconcentration under the conditions of the therapeutic regime In the thirty determinations of the specific gravity of the blood, no significant changes were found Apparently hemoconcentration is not the mechanism involved to account for the changes occurring in the blood cell count when fluids are administered during the course of treatment.

The rate and degree of fluid absorption undoubtedly are not the same for all patients Furthermore, the rate of perspiration varies not only from patient to patient, but with the same patient

from treatment to treatment [89] Gibson and Kopp[90] state that water may pass out of the blood stream more rapidly than it can be absorbed from the intestinal tract, and this fact has an important bearing on the determination of the optimal rate of fluid administration. It is also interesting to note that they found a direct relationship between the gross water loss and the environmental temperature of the patient. The water loss was greatest in those cases in which the differential temperature between the patient's body and his environment was highest, and least in those cases in which it was lowest. This observation is in agreement with the observation of Osborne (p 660). The environmental temperature of his patients, once the temperature plateau was reached, was usually below that of the rectum, or at the same level. This temperature was lower, somewhat, than the lowest recorded by Gibson and Kopp, and may account for the insignificant changes which Osborne found in the specific gravity of the blood

The Hemogram Caillet and Simonds[91] subjected mice to dry heat at 60° C. at intervals of ten days and found a marked leukopenia followed by a marked rise in the number of white cells soon after the heating The number of white cells reached a maximum ten to fourteen days later.

Knudson and Schaible,[92] working with dogs, found a considerable increase in red cells and hemoglobin They stated they found a marked increase in total white cells, due to an absolute and relative increase in the polymorphonuclears The lymphocytes and eosinophiles were decreased, but changes in the monocytes were less marked and less constant.

[89] Neymann, C A., and Osborne, S L. The Physiology of Electropyrexia. Am J Syph & Neurol 18 28 1934

[90] Gibson, J G, and Kopp, I Studies in the Physiology of Artificial Fever I Changes in the Blood Volume and Water Balance, J Clin Invest. 17 219 1938

[91] Caillet, O R., and Simonds, J P · Repeated Exposure to High Temperatures, Arch Pathol 8 622 1927

[92] Knudson, A., and Schaible, P J · Physiological and Biochemical Changes Resulting from Exposure to an Ultra High Frequency Field Arch. Path 11 728 1933

On the other hand, Hinsie and Carpenter[93] found a slight reduction in red blood cells as well as a decrease in hemoglobin An increase of polymorphonuclears and a relative decrease in lymphocytes were found Hinsie and Blalock[94] reported a seventy five per cent increase in the leukocyte count, which usually reached its peak at the end of the ninth hour, regaining its normal level at the end of about twenty hours The leukocytosis, they stated was characterized by an increase in the percentage of polymorphonuclears at the expense, chiefly, of the lymphocytes They also found an increase in the non filameotous forms Tenny[95] made similar observations

Feinberg, Osborne, and Steinberg[96] reported an average increase of red blood cells Eighteen cases showed an increase of leukocytes, neutrophilic polymorphonuclears, and transitional cells They also demonstrated a decrease in the eosinophile cells This investigation was made entirely on asthmatics

Perkins[97] made a study on general paretics, giving each patient ten consecutive fever treatments during a period of two weeks Each patient's temperature curve was made no simulate that of a malarial fever He concluded that the only effect of the treatment on the red cell count was to lessen the lability of the cells which characterized them prior to treatment The leukocytosis persisted for three days

Bierman[98] found a reduction of twenty to thirty per cent in the leukocyte count during the first two hours of fever induction This initial decrease was followed by a leukocytosis which reached

[93] Hinsie L. E. and Carpenter C M Radiotherm Treatment of General Paralysis Psychiat. Quart 5 215 1931

[94] Hinsie L E. and Blalock J R Leucocytes in General Paralysis Treated by Radiothermy Psychiat. Quart. 5 432 1931

[95] Tenny C. F Artificial Fever Produced by Short Wave Radio and its Therapeutic Application Ann. Int. Med. 6 457 1932

[96] Feinberg S H Osborne S L and Steinberg M J Sustained Artificial Fever in the Treatment of Intractable Asthma J A.M.A 99 801 1932

[97] Perkins C T Hyperthermia in Dementia Paralytica. Arch. Phy Therap 14 461 1933

[98] Bierman W The Effect of Hyperpyrexia Induced by Radiation Upon the Leucocyte Count Am. J Med Sci. 187 545 1934

a maximum in about six to nine hours The increased white cell count was attributed mainly to changes in the total number of neutrophiles, of which the staff neutrophiles showed the greatest increase He showed an increase in polymorphonuclears and a corresponding lymphopenia. He also reported an increase in red cells, and in many instances a marked increase of the immature forms These changes, he concluded, indicated a stimulation of bone marrow.

Phillips[100] stated that he found a temporary increase of approximately ten per cent in the red cell count during hyperpyrexia He reported an increase in total white cells The polymorphonuclears showed a ten to fifteen per cent increase Phillips did not believe the changes found were due entirely to dehydration.

Cohen and Warren[101] studied ten patients, each of whom received eleven treatments The temperature was maintained at 40.5° C. to 41 6° C. for five and three-quarters hours One patient was kept at a temperature of 41 6° C for twenty-one hours After control observations, hourly determinations of the blood count were made after the temperature reached the desired level Determinations were also made for several hours following termination of the treatment Blood studies were then continued at intervals until the patient left the hospital Although a leukocytosis was found in every case, the maximum change, the onset, the duration, and the extent of the change during the maintenance of the fever varied from patient to patient. A relative and absolute increase of polymorphonuclear leukocytes was observed during or immediately following the febrile period There was a substantial relative and absolute increase in immature polymorphonuclears in six of the eleven patients The red blood cell count showed a slight rise, and so did the hemoglobin, during or immediately following the period of fever. In one single instance, immature red cells were found These investigators stated that these observa-

[100] Phillips, K · Physical Methods of Fever Production from a Physiologic Viewpoint Arch. Phy Therap 19 473.1938

[101] Cohen, P , and Warren, S L A Study of the Leucocytosis Produced in Man by Artificial Fever J Clin. Invest. 14 423 1935.

tions suggested a mobilization into the circulation of available and nearly mature cells of the myeloid and erythrocytic series as a result of fever, while the cells of the lymphoid series decreased They could offer no explanation for the fall in lymphocytes They stated it was not clear whether those cells are stored somewhere in the body or take some specific part in attacking the pathological process present or are destroyed by the febrile reaction

Simon[102] studied ten patients to whom a total of seventy one

TABLE 68

EFFECT OF HYPERPYREXIA ON BLOOD COUNT

Cells	Before Treatment	At Height of Fever	After Treatment	24 Hours Later
Red Cell Count in Millions	4 7	5 3	—	5 3
White Cells	8 218	12 033	10 755	8 319
Polymorphs	58	70	72	86 8
Lymphocytes	37	28	22	39
Monocytes	4 5	1	4 6	1
Transitionals	2	1 5	—	1 9
Basophiles	1	1	0	0
Eosinophiles	1 9	1 4	1 4	1 6

treatments was administered He found a leukocytosis and an increased hemoglobin content This he thought was due in part to blood concentration He reported an increase of thirty per cent of the non filamentous cells It is evident, he stated that the bone marrow responds more quickly than the lymphatic system as shown by the relative decrease of lymphocytes According to him stimulation of the lymphatic system occurs but more slowly than that of the white cell forming organs

The results obtained by Osborne[103] in his study of fifteen patients are in essential agreement with those of the foregoing investigators His results are summarized in Table 68

[102] Simon J F Effects of Hyperpyrexia on the Human Blood Count Blood Chemistry and Urine. J Lab & Clin Med 21 400 1936

[103] Osborne S L Physiology of Hyperpyrexia Dissertation for the Doctorate Northwestern University Evanston 1940

Krusen[104 105] reported observations on one hundred patients whose temperatures ranged from 104° F to 106 8° F for three to seven hours He found a marked leukocytosis and a slight increase of the red cells, which he believed was due to blood concentration No change was found in the hemoglobin Like other investigators, he *observed an increase in the neutrophils* and a *decrease in the* lymphocytes, which he stated could not be due to blood concentration He noted a slight shift (2 7 per cent) to the left, although not comparable to the marked shift produced by malarial inoculations In discussing the work of Krusen,[105] Hargraves states

The work did not take into consideration the succession of changes *that occur for the next twenty hours following the onset of fever*, and hence might be misleading and mask the true post febrile picture If this period is studied with multiple serial counts, say at intervals of half an hour, a rather constant response will be found The response is so constant that we feel that the term febrile homogram is justified It is characterized by a post febrile leukocytosis the duration and extent of which is an individual affair, and bears a relationship to the duration and height of the fever The peak of leukocytosis is dependent on a polymorphonuclear increase and often goes as high or higher than 40,000 leukocytes per cu mm total white cell blood count It is here *that the younger cells, as shown by a changing filament nonfilament* ratio, are increased, this is evidence of bone marrow delivery and not a redistribution phenomenon As the polymorphonuclear peak declines, the total count is usually sustained, or partially sustained by an influx of monocytes The last cell to reappear in numbers is the lymphocyte *which usually assumes lymphopenic proportions during the episode of* fever

According to Doan[106] the majority of the cells making up the postfebrile leukocytosis are polymorphonuclear neutrophiles, newly delivered by the bone marrow as evidenced by their youth This

[104] Krusen F *Studies on the Blood Picture Before and After Fever Therapy* Abstracts of Papers and Discussions Fifth Annual Fever Conference May 1935

[105] Krusen F The Blood Picture Before and After Fever Therapy Am J Med Sci 193 470 1937

[106] Doan, C A. Peripheral Blood Phenomenon and Differential Responses of Bone Marrow and Lymph Nodes to Hyperpyrexia Radiology 30 382 1938

reaction, he believed, may be nonspecific and by no means necessarily the most important from the standpoint of the fundamental body defenses. Doan showed by means of lymph node studies that there is a destruction of lymphocytes during hyperpyrexia. Moreover, as further evidence of this lymphocytic destruction he cites the regeneration and delivery of new lymphocytes to the peripheral blood in the post febrile period He believed there was probably some destruction or redistribution of monocytes as shown by a delayed monocytosis, made up primarily of younger forms He stated that the hemograms following malaria and B-typhosis are quite different from those observed during fever induced by physical means. The shift to the left in the neutrophilic granulocytes in malaria is outstanding, and the appearance of clasmatocytes in the peripheral blood has been observed in no other type of fever.

Palitz[107] induced artificial fever in four unanesthetized dogs, raising their temperature two to four degrees Fahrenheit and maintaining it for one or two hours. He reported an absolute and relative increase in the formed elements of the blood These changes, he found, did not occur in the splenectomized animal The increased red cell count, he thought, could be explained by contraction of the spleen He stated that contraction of the spleen might be due to a nervous mechanism (a view held by Barcroft and Elliot), or a shift of blood from the viscera to the periphery, or an oxygen want.

Doan,[108] in an endeavor to determine whether the increase in circulating cells was due to splenic contraction, subjected a patient to an adrenaline test during hyperpyrexia, following which the blood picture showed little change other than a moderate increase in lymphocytes. He also subjected a splenectomized patient to four hours of fever of 106 to 107° F. A leukocytosis of 50,000 was reached, he stated, by the same tide-like variations as in

[107] Palitz, L L · Splenic Volume and the Polycythemia of Artificial Fever in Intact Unanesthetized Dogs Am. J Physiol 125 607 1939

[108] Doan, C A · Peripheral Blood Phenomenon and Differential Responses of Bone Marrow and Lymph Nodes to Hyperpyrexia, Radiology 30 382 1938

normal individuals. Cyanosis has been recognized as a stimulus to the spleen and bone marrow. Doan had the opportunity to observe a patient who became excited, cyanotic, and finally passed into an epileptic seizure. He reported that such an episode had no significant effect on the curve of leukocytosis.

Sloan and Doan[109] have shown that artificially induced fever decreased prothrombin and fibrinogen. They reported their results on four young adult individuals, normal except for some type of gonorrheal infection Fever with a temperature of 104° to 107° F. was induced with the Kettering Hypertherm and maintained from nine to ten hours, with a resultant relative and absolute thrombocytopenia. They found megakaryocytes in the bone marrow with definite cytoplasmic and nuclear damage The degree of thrombocytopenia, they stated, depended upon the extent of the megakaryocytic damage They pointed out that the pathogenesis of hemorrhage in artificially induced fever may be followed in orderly sequence; the elevation of body temperature results in anoxia and a depletion of liver glycogen; these factors may result in *hepatic and megakaryocytic damage, following which there is* a decrease in prothrombin and circulating platelets. Fibrinogen, they stated, may also be decreased The pointed out that the regeneration of the damaged parenchymatous tissues apparently takes place quite promptly and completely, the change being reversible. Their patient's normal equilibrium was reestablished in five to seven days The most marked decrease of prothrombin occurred during the twenty-four hour period following treatment.

Fetter and Schnabel[110] studied the behavior of blood sedimentation rate during and after fever therapy. They studied 41 patients whose temperature ranged from 104 to 107° F. They concluded that for practical purposes physically induced hyperpyrexia as used therapeutically does not affect the sedimentation rate.

The Carbon Dioxide Combining Power of the Blood. While studying the physiological effects of hot water baths on human

[109] Sloan, J W, and Doan, C. A.: The Pathogenesis of Hemorrhage in Artificially Induced Fever Ann. Int. Med 13.1215.1940.

[110] Fetter, F, and Schnabel, T. G: Behaviour of Blood Sedimentation Rate During and After Fever Therapy Am. J Med. Sci 201.115:1941

subjects, Hill and Flack[111] in 1909 found a rise of body temperature was accompanied by a reduction of the alveolar carbon dioxide tension A decrease in the CO_2 combining power of the blood has been observed by a number of investigators

The first blood chemistry studies to appear in which the method of internal heating was employed were those of Bischoff Ullman Hill, and Long[112] in 1930, and those of Bischoff, Long and Hill[113] in 1931 They found a fall in the total CO_2 content of the blood of four to twelve per cent by volume Mortimer[114] in 1931 working with dogs, found a decrease in the plasma CO_2 combining power in dogs amounting to as much as twenty per cent In the same year, Neymann and Osborne[115] reported ten observations made on a single individual, showing a decrease in the plasma CO_2 combining power of the blood Feinberg Osborne and Steinberg[116] while studying the effects of artificial fever in the treatment of intractable asthma reported that the CO_2 combining power of the plasma decreased They made seventy determinations and the average decrease was found to be eight per cent They also stated that with high fever, there was in three instances an increase in the CO_2 combining power of the blood of more than ten per cent by volume In fourteen instances the change was less than five per cent either way Hopkins[117] in 1934 made chemical blood studies of twelve patients using the hot water bath to induce hyper

[111] Hill L. and Flack M The Influence of Hot Baths on Pulse Frequency Blood Pressure Body Temperature Breathing Volume and Alveolar Tensions in Man J Physiol 38 57 1909

[112] Bischoff F Ullmann H. J Hill E and Long M L Studies in Hyperthermia Induced by the High Frequency Electric Current J Biol Chem 85 675 1930

[113] Bischoff F Long M L and Hill E. Acid Base Equilibrium in Hyperthermia Induced by Short Radio Waves J Biol Chem. 90 321 1931

[114] Mortimer B Experimental Hyperthermia Induced by High Frequency Current Radiology 16 705 1931

[115] Neymann C A. and Osborne S L The Treatment of Dementia Paralytica With Hyperpyrexia Produced by Diathermy J.A.M.A. 96 7 1931

[116] Feinberg S H Osborne S L and Steinberg M J Sustained Artificial Fever in the Treatment of Intractable Asthma J.A.M.A. 99 801 1932

[117] Hopkins H Chemical Changes in the Blood Induced by Hyperpyrexial Baths Arch Neuro & Psych 31 597 1934

pyrexia, and reported a decrease of the total CO_2 combining power amounting to five per cent Krusen,[118] using the Kettering Hypertherm for the production of artificial fever, reported in 1935 that the average decrease of the CO_2 combining power of the blood was ten volumes per cent for one hundred treatments at 104° F to 106 8°F. Phillips and Shikany[119] in 1935 reported on the blood chemistry of nine patients undergoing fever therapy for the treatment of asthma Four of their patients showed a decreased CO_2 content of alveolar air, one an increase, and four no change at all

Osborne[120] in 1940 reported the result of twenty-six determinations made on six patients undergoing fever therapy. The average carbon dioxide combining power just before treatment was 51 4 volumes per cent, the standard error being ±1 4. Immediately after treatment, the average dropped to 45 8 volumes per cent with a standard error of ±1 2 The average decrease of the carbon dioxide combining power of the plasma, therefore, was 5 6 volumes per cent Twice the standard error difference was 3 6, so that the decrease is quite significant

Looney and Borkovic[121] in 1942 studied the changes produced in the oxygen and carbon dioxide content of arterial and venous blood of the brain of twelve patients during hyperpyrexia They reported that the increased rate of respiration resulted in washing out of carbon dioxide, as shown by the progressive fall in both arterial and venous carbon dioxide, amounting to 4 16 volumes per cent for the former and 4 31 volumes per cent for the latter

The interpretation of the pH and acid-base changes in the blood is not easy This is due principally to the fact that simultaneous

[118] Krusen F Studies on the Blood Picture Before and After Fever Therapy Abstracts of Papers and Discussion, Fifth Annual Fever Conference, May, 1935

[119] Phillips, K, and Shikany, S The Value of Hyperpyrexia in the Treatment of Bronchial Asthma Southern Med J 28 801 1935

[120] Osborne, S L Physiology of Hyperpyrexia, Dissertation for the Doctorate, Northwestern University, Evanston, 1940

[121] Looney, J M, and Borkovic, E J Changes Produced on Oxygen and Carbon Dioxide Content of Arterial and Venous Blood of Brain During Diathermy Therapy for General Paresis Am J Physiol 136 177 1942

determinations of pH, acid-base balance, and alveolar carbon dioxide tension have not been made The interpretations are varied Bazett and Haldane[122] believed that the respiratory center becomes more sensitive to carbon dioxide with a rise in body temperature; hence fever will tend to produce hyperpnea, Koehler[123] thinks it is altogether probable that when there is a definitie oxygen want in the tissues, there results an anoxemic stimulation of respiration He states that in addition to the stimulation of respiration by an increased CO_2 content of the blood, there is a possibility that stimulation of respiration also results from a change in the hydrogen ion concentration—an explanation long held as to the mechanism of stimulating the respiratory center. Cajori, Crouter, and Pemberton,[124] on the other hand, do not agree with Koehler that there is always an increase in the oxygen saturation of the venous blood following the increase of the blood pH Bischoff, Long, and Hill[125] state that the change in the total carbon dioxide content of the blood is readily accounted for by the shift of base to the blood proteins due to the increased pH of the blood They found no evidence to believe that the body attempts to compensate for the lowered CO_2 tension by lowering alkali reserve In fact, both Cajori and Bischoff found evidence of a slight increase in the alkali reserve It would appear that the $\frac{BHCO_3}{HCO_3}$ ratio is changed with either no change or a slight rise in the $BHCO_3$, and a decrease in the HCO_3 Bazett and Haldane[126] reported that the symptoms of faintness, mental confusion, and tingling of the extremities was experienced by some of their subjects exposed to the hot water bath One of the subjects had marked hyperpnea These workers

[122] Bazett, H C., and Haldane, J B Some Effects of Baths on Man J Physiol 55· Proceedings No 4 1921

[123] Koehler, A E Acid Base Equilibrium I Clinical Studies in Alkalosis Arch. Int Med 31 590 1923

[124] Cajori, F A., Crouter, C Y, and Pemberton, R Effects of Heat on Acid Base Balance J Biol Chem. 57 217 1923

[125] Bischoff, F, Long, M L, and Hill, E Acid Base Equilibrium in Hyperthermia Induced by Short Radio Waves J Biol Chem 90 321 1931

[126] Bazett, H C., and Haldane, J B · Some Effects of Baths on Man J Physiol 55 Proceedings No 4 1921

felt that while hyperventilation played an important role in the production of these symptoms, a too rapid rise of the body temperature might well be a contributing factor. Landis, Long, Dunn, Jackson, and Meyer[127] believed that the factors which seemed to influence the fall in alveolar CO_2 were chiefly the rate of ventilation, the type of breathing, and the length of the experimental period They found, as might be expected, that the total CO_2 content of the blood was reduced in general according to the degree of hyperpnea

Desjardins,[128] in a discussion of Lepore's paper on chloride and water balance in relation to fever, stated: "Another point that might be mentioned, largely as a question, refers to the tetany that is encountered in a few patients We had one patient . . . who . . . had it in the abdominal muscles. Ten cubic centimeters of calcium gluconate did not relieve the tetany. A short time later a second injection was given, and that also failed to stop the tetanic contractions Carbon dioxide and oxygen were then given and this was followed by immediate relief. . . This experience led us to think that overventilation probably is the chief cause of the tetany."

Bazett and Haldane[129] found that the distressing symptoms, mentioned in the preceding paragraph, were instantly relieved by breathing 8 5 per cent CO_2, or by re-breathing expired air This indicates that acapnia, or a depressed respiratory center, was present in their subject It would seem, as we have already pointed out, that instead of supplying the very distressed patient with oxygen, as has been the tendency, it might be far more effective to give 8 5 per cent of CO_2, or have the patient rebreathe his expired air. In the presence of cyanosis, 5 per cent CO_2 and 95 per cent oxygen might be preferable The period of greatest hyperventilation is during the fever induction, and is particularly *evident when external heating methods are used* As a general

[127] Landis, E M, Long, W H, Dunn, J W, Jackson, C L, and Mayer, Y · Studies on the Effects of Baths on Man Am J Physiol 76 35·1926

[128] Desjardins, A U Abstracts and Papers and Discussion Fifth Annual Fever Conference, Dayton Ohio, 1935

[129] Bazett, H. C, and Haldane, J B *Some Effects of Baths on Man* J Physiol. 55: Proceedings No 4: 1921.

rule, once the desired temperature has been reached, the respiratory changes quiet down considerably. Therefore, the use of CO_2 to increase the depth of respiration during the stages of fever induction might be of considerable value in some instances

Non-Protein Nitrogen and Urea Nitrogen of the Blood Neymann and Osborne[130] in 1931 noted an increase in the non-protein nitrogen and uric acid in the blood of their paretic patients while undergoing fever treatment In the same year Bischoff, Long, and Hill[131] stated that they found a slight increase in the blood non-protein nitrogen and urea nitrogen. At about the same time Nasset, Bishop, and Warren,[132] working with anesthetized dogs, reported a marked increase in non-protein nitrogen values In 1931 Knudson and Schaible[133] also reported that both the non-protein nitrogen and urea nitrogen of the blood were increased in proportion to the temperature of the dog and the duration of the fever. Mortimer[134] in 1931, also working on anesthetized dogs, made a similar observation Feinberg, Osborne, and Steinberg,[135] studying the value of hyperpyrexia in the treatment of asthma, reported in 1931 that they found an increased non-protein nitrogen and urea nitrogen content of the blood in the majority of their patients On the other hand, Cameron[136] in 1933 stated that he found no change in the total nitrogen Phillips and Shikany[137] in 1935 state that they made

[130] Neymann C A, and Osborne, S L The Treatment of Dementia Paralytica with Hyperpyrexia Produced by Diathermy J A.M A 96 7 1931

[131] Bischoff, F, Long M L, and Hill, E · Acid Base Equilibrium in Hyperthermia Induced by Short Radio Waves, J Biol. Chem 90 321 1931

[132] Nasset, E. S, Bishop, F W, and Warren, S L · Physiological Effects of High Frequency Current, Am J Physiol 96 439 1937

[133] Knudson, A, and Schaible, P J Physiological and Biochemical Changes Resulting from Exposure to an Ultra High Frequency Field Arch. Path 11 728 1933

[134] Mortimer, B Experimental Hyperthermia Induced by High Frequency Current Radiology 16 705 1931

[135] Feinberg S H, Osborne, S L, and Steinberg, M J Sustained Artificial Fever in the Treatment of Intractable Asthma J A M A. 99 801 1931

[136] Cameron, A. J D · Electropyrexia. The Medical Press and Circular, London, 1933

[137] Phillips, K., and Shikany, S The Value of Hyperpyrexia in the Treatment of Bronchial Asthma. Southern Med J 28 801 1935

a study of fifty consecutive asthmatic patients while undergoing fever therapy and found very little variation in the non-protein and urea nitrogen.

The observations in Table 69 were made on a single individual, because so few repeated determinations have been made on the same subject while undergoing fever therapy.

In addition to the non-protein nitrogen and uric acid values, other determinations that were made at the same time are also shown The average value of the non protein nitrogen increased from 22 5 to 26 4 mg per 100 cc It is interesting to note that there was an almost steady decrease in the n p n from treatment to treatment, so that while it was 32.4 mg per 100 cc at the beginning of the treatment, it had dropped to a level of 15 0 mg per 100 cc by the tenth treatment The uric acid increased from an average value of 3.7 to 4 7 mg per 100 cc. The value at the tenth treatment was higher than the initial one.

The average n p n increase of 3 9 mg per 100 cc of blood is well within the range of the changes reported by Bischoff, Long, and Hill,[138] namely, 2 3 mg per 100 cc. Feinberg, Osborne, and Steinberg[139] reported an average increase of 2 8 As previously noted, both Phillips[140] and Cameron[141] state they found no change Animal experimentation on the other hand shows a far greater increase in the non-protein nitrogen Knudson and Schaible[142] reported that at a temperature of 107° F., there was a ten per cent increase, while at a temperature of 110° F, the average value showed an increase of 75 per cent. They found a marked decrease in blood volume which they attributed to fluid loss. This would seem

[138] Bischoff, F, Long M L, and Hill, E Acid Base Equilibrium in Hyperthermia Induced by Short Radio Waves J Biol Chem 90 321 1931

[139] Feinberg, S H, Osborne, S L, and Steinberg, M J · Sustained Artificial Fever in the Treatment of Intractable Asthma, J A M A 99 801 1932

[140] Phillips, K · Physical Methods of Fever Production from a Physiologic Viewpoint. Arch. Phy Therap 19 473 1938

[141] Cameron A J D Electropyrexia The Medical Press and Circular, London, 1933

[142] Knudson, A, and Schaible, P. J Physiological and Biochemical Changes Resulting from Exposure to an Ultra High Frequency Field. Arch. Path 11 728 1933

TABLE 69

THE EFFECT OF HYPERPYREXIA ON THE BLOOD CHEMISTRY OF AN INDIVIDUAL PATIENT

Date of Observation	Calcium in Serum mg per 100 cc		Chlorides in Blood mg NaCl per 100 cc		Carbon Dioxide Capacity of Plasma		Non Protein Nitrogen mg per 100 cc.		Uric Acid mg per 100 cc	
	Before	After	Before	After	Before	After	Before	After	Before	After
E B										
7 5 29	10 6	11 6	427	413	62 cc	54 6	32 4	37 5	3 28	4 28
7 8 29	—	10 6	433	460	57	55	33 3	36 6	3 36	4 34
7 11 29	—	—	464	466	55 4	50 5	20 2	24 4	4 06	4 92
7 15-29	10 2	10 7	445	454	55 4	52 2	26 08	27 8	4 10	5 02
7 18 29	10 6	11 0	438	449	53 8	51 3	24 0	27 77	4 18	5 86
7 22 29	10 2	10 8	442	456	54 6	50 5	23 6	27 3	3 36	4 4
7 25 29	9 4	10 7	464	466	57 0	49 7	18 7	22 4	3 84	4 6
7 30-29	9 0	10 4	476	473	55 4	51 3	15 4	20 2	3 4	4 1
8 2 29	9 3	10 7	473	449	55 4	49 7	16 5	24 4	3 6	4 5
8 6 29	10 0	11 1	473	414	49 7	44 0	15 0	15 8	3 84	4 94
Averages	9 9	10 8	453	450	55 6	51 4	22 5	26 4	3 7	4 7
Average Change	+0 9		−3		−4 2		+3 9		+1 0	

reasonable since they gave their animals no fluid This debydration factor consequently obscures the effect which the temperature elevation exerted itself, and it seems likely that tbe blood changes they noted were due chiefly to dehydration However, they state tbat in many of their experiments the increase was entirely out of proportion to the blood concentration Moen, Medes and Chalek[143] studied the effect of artificially induced fever on dogs, in which attempts were made to overcome the dehydration factor They noted only minor changes in both total plasma protein and the plasma-protein fractions of tbese dogs No data were given concerning non protein nitrogen

In seven patients with Bright's Disease, Farr and Moen[144] reported that no significant direct relationship between fever and the urea clearance was noted Goldring[145] found the urea clearance sligbtly elevated in active febrile rheumatic fever; and Farr and Abernethy[146] found a marked elevation of the urea clearance in pneumonia, which was not related to temperature

In dogs, Van Slyke, Rhoads, Hiller, and Alving[147] found that the urea clearance varied in direct proportion to the renal blood flow According to Farr and Moen,[148] the mechanism producing the lowered clearance was presumably a retarded renal blood flow, and the possible causes of the retarded renal circulation may have been either deflection of blood from the kidneys to the byperemic skin, or occurrence of some desiccation despite the precautions taken

[143] Moen, J K, Medes, G, and Chalek, I The Relative Effects of Diathermy and Infection on the Plasma Proteins, Plasma Viscosity, and Suspension Stability of the Blood in Dogs J Lab & Clin Med 19 571 1934

[144] Farr, L E, and Moen, J K The Effect of Induced Hyperpyrexia on the Urea Clearance of Rheumatic Patients Am J Med Sci 197 53 1939

[145] Goldring, W Studies of the Kidney in Acute Infection J Clin Invest 10 345 1931

[146] Farr, L E, and Abernethy, T J Renal Physiology in Lobar Pneumonia J Clin Invest 16 421 1937

[147] Van Slyke, D D, Rhoads, C P, Hiller, A., and Alving, A S The Relationship of the Urea Clearance to the Renal Blood Flow Am J Physiol 110 387.1934

[148] Farr, L E, and Moen, J K· The Effect of Induced Hyperpyrexia on the Urea Clearance of Rheumatic Patients Am J Med Sci 197 53 1939

to prevent it The decrease in renal function was not serious in any of the patients, and was transitory The fact that a definite decrease occurred, however, emphasized the desirability of combatting desiccation during the febrile treatment, and of applying such treatment with caution to patients with damaged kidneys, until the effect of artificially induced fever in such patients has been studied

Nicholes, Boynton, and Herrin[149] studied the changes in creatinine clearance and urine flow of a few animals during fever The temperature was elevated from one to three degrees Fahrenheit and maintained for a very short period During the maximum hyperthermia they often found an oliguria. The plasma creatinine clearance decreased 13 to 45 per cent. It never significantly increased They concluded that an increase in creatinine clearance was never due to the hyperthermia itself, but rather to changes in the tissues which are responsible for the hyperthermia

Nasset, Carr, and Peters[150] noted in their dogs instances of a two hundred per cent increase They attributed these high values, however, to tissue destruction which frequently occurred at the site of application Mortimer[151] found a change of 3 7 mg per 100 cc. for his animals, whose temperature varied from 106° to 109° F. Nasset, Carr, and Peters[1] stated that at temperatures beyond 107 6° F. there was a very marked increase

Undoubtedly a contributing cause of the increase in non protein nitrogen is the increased basal metabolism Also with the rise in body temperature an oliguria occurs with the production of metabolites, which continues whether the urine is excreted or not, resulting in an accumulation of an excess in the body Bischoff, Long, and Hill[152] state that these increases were comparable to the

[149] Nicholes, H J, Boynton, B L, and Herrin, R. C Changes in Creatinine Clearance and Urine Flow of Dog During Fever J Lab & Clin Med 27 1306 1942

[150] Nasset, E. S, Carr, J W, and Peters, S B Dehydration in Hyperthermia Produced by High Frequency Current Proceed Am Physiol Soc Am J Physiol 101 78 1932

[151] Mortimer, B Experimental Hyperthermia Induced by High Frequency Current Radiology 16 705 1931

[152] Bischoff, F, Long, M L., and Hill, E. Acid Base Equilibrium in Hyperthermia Induced by Short Radio Waves J Biol Chem 90 321 1931

change in the oxygen capacity. Nasset, Bishop, and Warren[153] believe that the smaller increases in non-protein nitrogen are due primarily to blood concentration

According to Gibson and Kopp[154] the question of blood concentration is far from settled. They criticize the technique used by previous workers in arriving at their conclusions, and one is led to believe that they doubt whether there is any significant blood concentration The high n p n. values obtained in animal experimentation undoubtedly are due to tissue damage resulting from electrical burns. This tissue damage frequently is in the subcutaneous layers, and hence it is quite possible that many of the early workers may not have noted these burns below the surface. As Nasset, Bishop, and Warren[155] stated, these burns might account for the high values found in their dogs It must not be overlooked, however, that the body temperature in the human subjects was not carried to as high a level as was that of the dogs, although it was sustained in most instances over a longer period of time

In our patient there was no evidence to indicate that repeated hyperpyrexia causes kidney damage This view is corroborated by the work of Neymann, Lawless, and Osborne[156] who subjected one of their patients, who had had one kidney removed, to a series of fever treatments at 106 5° F., each treatment being maintained at this level for a period of 5 hours No evidence of kidney damage was found by the usual clinical laboratory tests

Pulse Volume Changes Johnson, Osborne, and Scupham[157] studied the pulse volume changes that occur during artificial fever in an attempt to ascertain the extent of the peripheral vascular

[153] Nasset, E S, Bishop, F W, and Warren, S L Physiological Effects of High Frequency Current. Am. J Physiol 96·439 1937

[154] Gibson, J G, and Kopp, I · Studies in the Physiology of Artificial Fever I Changes in the Blood Volume and Water Balance J Clin Invest 17 219 1938

[155] Nasset, E S, Bishop, F W, and Warren, S L. Physiological Effects of High Frequency Current Am J Physiol 96 439 1937

[156] Neymann, C A, Lawless, J K., and Osborne, S L. The Treatment of Early Syphilis with Electropyrexia. J.A M.A 107 194 1936

[157] Johnson, C. A., Osborne, S L, and Scupham, G The Effect of Artificial Fever on the Pulse Volume Changes of the Finger Am J Med Sci 190 485·1935

change, and at what temperature the maximum change occurs The circulatory changes were measured in one finger by means of the Johnson air conduction plethysmograph From the photographic record obtained with this device it was possible to estimate a 0 002 cc. volumetric change Before fever, the pulse volume varied from 0 01 to about 0 05 cc.

In each experiment, artificial fever at approximately 104 5°, was induced and maintained for eight hours The interval between each fever treatment was seven days They found that the maximum increase in pulse volume occurred at a temperature of 103° to 104° F. They interpreted the change in the pulse volume as being indicative of a change in peripheral circulation

Once the maximum amplitude of the excursion, ranging from 0 043 to 0 08 cc., was reached, the pulse volume fluctuated from hour to hour and gradually decreased with falling temperature When the rectal temperature returned to normal, the amplitude of the excursions returned to the control level or slightly above

Further measurements have been reported by Osborne, Markson, Driscoll, and Merriman,[194] using the method already referred to. Curves 1 to 5 inclusive of Fig 234 show the variation of pulse volume with change in temperature during the course of a four hour treatment These are in agreement with the curves obtained by Johnson, Osborne, and Scupham From the experimental evidence presented, it would appear that maximum vasodilatation is obtained when the rectal temperature is in the neighborhood of 104° F.

Johnson, Osborne, and Scupham interpreted the changes they observed as evidence of an increased circulation, resulting from vasodilatation and a probable increased cardiac output They stated that their interpretation was undoubtedly open to some question Furthermore, they stated that they were not unmindful of the fact that the factors which maintain blood pressure, such as the resistance of the soft tissues, also affect the extent of the excursion recorded by this device It might be possible to have an

[194] Osborne, S L, Markson, D E, Driscoll, R E, and Merriman J R Treatment of Arthritis by Electropyrexia J Lab & Clin Med 27 1135 1942

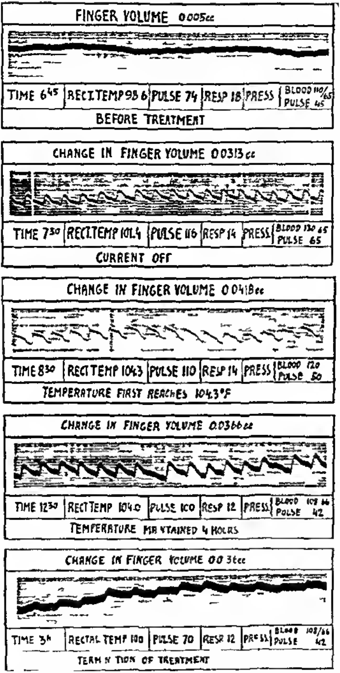

FIG 234 Plethysmographic tracings showing change in the pulse volume of the finger with change in temperature (From Osborne Markson Driscoll and Merriman Jour Lab and Clin Med. 27 11 35 1942)

increased circulation without increased pulsation, but not possible to have an increased pulsation without increased circulation

The striking feature was that the maximum response occurred at the temperature of 103° F. to 104° F., which was considerably lower than the maximum temperature attained Furthermore, the amplitude of the excursions, which indicates the circulatory response, showed marked variations as the temperature was maintained This was interpreted as due to instability of the vasomotor system. These results indicate that there may be an optimal temperature at which a maximum circulatory response occurs This suggests that where increased circulation is the main therapeutic objective, the patient's temperature should not exceed 103° to 104° F.

Other investigators have measured the velocity of blood flow Kissin and Bierman[139] studied the relation between body temperature and the circulation time They injected small measured doses of sodium cyanide intravenously. The time from the end of the injection to the first deep breath was measured with a stop watch This interval was taken as the circulation time They found that the circulation time decreased as the body temperature rose, and conversely, the circulation time increased as the temperature fell The blood velocity was not always proportional to the temperature, nor to the pulse rate, but followed the temperature more closely than it did the pulse

Kopp[140] measured the arm to tongue velocity time by the decholin method He induced fever in two patients with dementia paralytica, one of whom had a syphilitic aortic regurgitation and cardiac hypertrophy. During the second half of the fever treatment administered to the patient with an apparently normal heart, an increase of the basal velocity of flow occurred, and was accompanied by an increase in the pulse rate The basal velocity of blood flow of the patient with syphilitic heart disease tended also to

[139] Kissin, M, and Bierman, W Influence of Hyperpyrexia on Velocity of Blood Flow Proc. Soc Exp. Biol & Med 30 527 1935

[140] Kopp, I Velocity of Blood Flow in Therapeutic Hyperpyrexia Am. Heart Jour 11.475 1936

increase as fever therapy was continued, but was accompanied by a slowing of the pulse rate. He suggested that the changes in the basal velocity of blood flow and pulse rate of both patients were due to the beneficial effects of therapeutic fever on the myocardium, the changes in the patient with syphilitic heart disease resembling those characteristic of digitalis therapy. Like Kissin and Bierman[161] he found no absolute quantitative relationship between the percentage increase in the velocity of flow and the

TABLE 70

EFFECT OF HYPERPYREXIA ON BLOOD PRESSURE

	Before Treatment	After Treatment	Change	2σ diff
Average Systolic B P	129	108	21	7
Average Diastolic B P	83	69	14	6 4
Average Pulse Pressure	46	39	—	—

degree of temperature rise He also found that the velocity of flow was less marked during typhoid vaccine fever

Osborne[162] reported the effect of hyperpyrexia on the blood pressure of 24 patients Table 70 gives the statistical analysis of this data. The changes observed are statistically significant

The Influence of Hyperpyrexia on Ascorbic Acid It has been established that the plasma ascorbic acid concentation is lowered during the course of an infectious fever. Consequently, the therapeutic procedure of supplementing the diet of such patients with ascorbic acid has received increased attention

[161] Kissin, M , and Bierman, W · Influence of Hyperpyrexia on Velocity of Blood Flow, Proc. Soc Exp Biol. & Med. 30 527 1935

[162] Osborne, S L Physiology of Hyperpyrexia. Dissertation for the Doctorate Northwestern University, Evanston, 1940

Osborne and Farmer[163] undertook an investigation to ascertain whether artificial fever produced by physical means also produced a lowering of the plasma ascorbic acid The body temperature was elevated and maintained at 104 6° F (rectal) for a period of 4 hours, following which it was permitted to return to normal To induce and maintain the patient's temperature, induction heating combined with an air-conditioned cabinet was employed Treatments were given once weekly.

Seventy-seven observations were made on 17 patients Analytical determinations were made on each patient· (a) just prior to

TABLE 71

EFFECT OF HYPERPYREXIA ON ASCORBIC ACID CONCENTRATION IN THE BLOOD

	Elapsed time, hrs	Avg of 77 Determinations on 17 Chronic Arthritis Patients	σ	2σ diff	Change
Control	0	62	03		
Temp reached 104°F	2	68	04	104	06
Temp at 104° F 4 hrs	6	66	03	106	04
Temp returned to normal	8	64	03	088	02

treatment; (b) when the rectal temperature reached 104° F ; (c) after a temperature of 104° F. had been maintained for 4 hours, and (d) after the patient's temperature had returned to normal

Table 71 gives a summary of the average values and the result of the statistical analysis Obviously, there are no significant changes in the blood plasma ascorbic acid concentration during or following the course of the artificial fever

Investigators differ markedly in their opinions as to what constitutes a normal blood plasma ascorbic acid level, either in health or disease. Abt and Farmer[164] in their studies on children and young

[163] Osborne, S L , and Farmer, C J Influence of Hyperpyrexia on Ascorbic Acid Concentration in the Blood Proc Soc Exp Biol & Med 49 575 1942

[164] Abt, A. F , and Farmer, C J Titration of Plasma Ascorbic Acid as Test for Latent Atvitaminosis C. Proc Round Table, Nutrition & Pub Health 16 114 1938

adults, report normal values for patients with adequate intake ranging from 0 7 to 1 5 mg per hundred cubic centimeters Blood plasma values below 0 7 mg they consider to be suboptimal Furthermore, according to these investigators, active scurvy may *occur in children with values up to 0 4 mg per cent* Abt and Farmer believe that while these values are critical during the period of growth, they may not have the same significance in the adult Wolff, Banning, and van Eekelen[165] state a blood level of 0 4 to 1 2 mg per cent to be adequate but not the optimum Daum, Boyd, and Paul[166] state that the normal ascorbic acid content of the blood ranges between 0 7 to 2 0 mg per cent Ralli and Sharry,[167] in their recent review, agree that plasma levels of 0 7 mg per cent, or above, indicate a satisfactory state of vitamin C nutrition, provided they are accompanied by a white cell platelet content of 25 to 38 mg per cent

While the average blood plasma ascorbic acid concentration for our group was 0 62 mg per cent before treatment, the range varied from a low of 0 28 to 0 72 mg per cent Many of the values found in these patients are considered to be subnormal Thirty-three of the 77 determinations before treatment showed a level below 0 5 mg per cent This is of interest in the light of the work of Rhinehart,[168] who as the result of his study expressed the following opinion "On the basis of experimental data previously reported, the concept was presented that rheumatic fever may be the result of the combined influence of vitamin C deficiency and infection With respect to the role of infection, it may briefly be said that in the presence of adequate vitamin C nutrition, rheumatic type lesions have not been observed"

[165] Wolff L K Banning C and van Eekelen M Nutrition of Various Groups of Families in the Netherlands Showing Vitamin A and C Content, and Investigation of Blood and Urine for Presence of These 2 Vitamins Quart Bull Health Organ League of Nations 5 566 1936

[166] Daum K Boyd K and Paul W D Influence of Fever Therapy on Blood Levels and Urinary Excretion of Ascorbic Acid Proc Soc Exp Biol & Med 40 129 1939

[167] Ralli E P and Sherry H. Adult Scurvy and Metabolism of Vitamin C Medicine 20 251 1941

[168] Rinehart J F Studies Relating Vitamin C Deficiency to Rheumatic Fever and Rheumatoid Arthritis Experimental Clinical and General Considerations, Rheumatic Fever Ann Int. Med 585 9 1935

The claim has been made that fever increases the vitamin C requirement The most worthy evidence in support of this claim has apparently been submitted by Zoak and Sharpless [169] They subjected guinea pigs to a scorbutogenic diet and to artificial hyperpyrexia for from 2 to 6 hours daily Early in the course of the experiment they found the vitamin C content of the tissues reduced by hyperpyrexia, but as the scorbutic state was approached, little difference was found This was particularly true of the adrenals The evidence obtained from human subjects is divergent The conclusion of Zoak and Sharpless[169] that no significant change in the blood level of vitamin C occurs, was confirmed by the results of Osborne and Farmer They believed the failure to observe a decrease was due to hemoconcentration, however, studies by Osborne[170] failed to show a hemoconcentration during hyperpyrexia when produced by the methods and management which he employed On the contrary, Daum, Boyd, and Paul[171] observed a decrease in the blood plasma level Falke,[172] Daum Boyd and Paul,[173] and Zoak and Sharpless[174] studied urinary excretion of vitamin C as well as the blood level These investigators with the exception of Zoak and Sharpless, interpreted their data as showing that fever increases the need for or the utilization of vitamin C in man According to Falke,[172] who induced a fever with *pyrifer*, the need is increased by 100 mg per day Zoak and Sharpless expressed the view that by following the blood level and urine excretion one cannot accurately determine if fever increases the utilization of

[169] Zoak J and Sharpless G R Vitamin C Nutrition in Artificial Fever Proc Soc Exp Biol & Med 39 233 1935

[170] Osborne S L Hyperpyrexia and the Specific Gravity of Blood Arch Phys Therap 22-407 1941

[171] Daum K Boyd K and Paul W D Influence of Fever Therapy on Blood Levels and Urinary Excretion of Ascorbic Acid Proc Soc Exp Biol & Med 40 129 1939

[172] von Falke Über die Grosse des Vitamin C Verbrauche im Fieber Klin Wchschr 18 818 1939

[173] Daum K Boyd K and Paul W D Influence of Fever Therapy on Blood Levels and Urinary Excretion of Ascorbic Acid. Proc Soc Exp Biol & Med 40 129 1939

[174] Zoak J and Sharpless G R Vitamin C Nutrition in Artificial Fever Proc Soc Exp Biol & Med 39 233 1935

vitamin C, tissue analysis as performed in the guinea pig studies would seem to yield more direct evidence. The reliability of data on the urinary excretion in regard to the utilization of or need for vitamin C is questioned by Abt and Farmer,[175] and by Wolff, Banning, and van Eekelen [176] The blood plasma level would appear to be more reliable, since the level at which vitamin C appears in the urine is subject to considerable individual variation. Further, Hawley, Frazer, Button, and Stephens[177] present evidence indicating that the reaction of the urine is concerned in determining the excretion of vitamin C Finally, in man considerable vitamin C is lost through the sweat, according to the observations of Cornbleet, Klein, and Pace.[178] This, however, is denied by Wright and MacLenathan [179] Osborne and Farmer could not find a satisfactory method for the determination of the loss of vitamin C in sweat. They assumed that the blood plasma level is the best indicator for the body level of vitamin C. According to this view, using the blood plasma level as the criterion, they found that a body temperature of from 104° to 104.6° F. for 4 hours did not significantly or detectably increase the rate of utilization of vitamin C

VI. THE EFFECT OF HYPERPYREXIA ON IMMUNE BODIES Mendel[180] found that the usual lethal dose of streptococci was tolerated by rabbits, if these organisms had been exposed to temperatures varying from 40 5° C for twenty-four hours to 48° C

[175] Abt, A F, and Farmer, C J Titration of Plasma Ascorbic Acid as Test for Latent Avitaminosis C Proc Round Table Nutrition & Pub Health *16* 114 1938

[176] Wolff, L K, Banning, C, and van Eekelen, M Nutrition of Various Groups of Families in the Netherlands, Showing Vitamin A and C Content, and Investigation of Blood and Urine for Presence of These 2 Vitamins Quart Bull Health Organ League of Nations 5 566 1936

[177] Hawley, E E, Frazer, J P, Button, L L, and Stephens, D J, Effect of the Administration of Sodium Bicarbonate and of Ammonium Chloride on the Amount of Ascorbic Acid Found in the Urine J Nutrition *12* 215 1936

[178] Cornbleet, T, Klein, R J, and Pace, E R Vitamin C Content of Sweat, Arch Derm & Syph 34 253 1936

[179] Wright, I S, and MacLenathan E Intradermal Test for Vitamin C Determination. J Lab & Clin Med 24 806 1939

[180] Mendel, B Heitzetherapie, Klein Wchnsch 7 1898 1928

for fifteen minutes He stated it required almost one hundred times the lethal dose before all the injected animals were killed The mouse, he observed, is far more sensitive to streptococci than the rabbit, because the mouse does not respond with fever to the inoculation, while the rabbit does Based on these observations, he

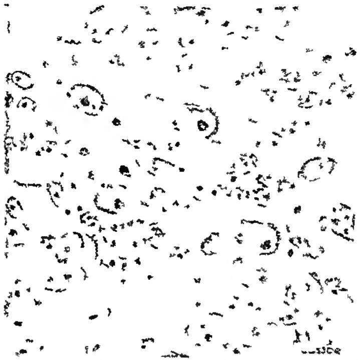

FIG 235 Fragmented and degenerated spirochetes in a histologic section of an inguinal lymph gland after three sessions of hyperpyrexia at temperatures above 105 8° F for more than two hours and above 107 6° F for approximately one hour during each session (From Neymann Lawless and Osborne J A M A 107 194 1936)

suggested the use of heat in the treatment of streptococcic infections in man

Feinberg, Osborne, and Steinberg[131] made quantitative studies on the skin and on the atopic reagins, before and after fever treatments for intractable asthma They found no decided changes

[131] Feinberg S H Osborne S L and Steinberg M J Sustained Artificial Fever in the Treatment of Intractable Asthma J A M A 99 801 1932

and concluded that the mechanism of relief could not be explained on that basis Hicks and Szymanowski [82] made similar observations on guinea pigs These workers also observed no changes in the precipitin titer in rabbits

Carpenter Boak and Warren [183] in discussing the results of their

FIG 236 Fragmented and degenerated spirochetes after three sessions of hyper pyrexia External skin temperatures and internal (rectal) temperatures were maintained above 105 8° F for one hour and above 107 6° F for an additional hour (From Neymann Lawless and Osborne J A.M A 107 194 1936)

experiments, in which they treated rabbits inoculated with the treponema pallidum, stated

[82] Hicks R A and Szymanowski W T The Biologic Action of Ultra High Frequency Currents J Infect Dis 50 466 1932

[183] Carpenter C M Boak R. A and Warren S L IV The Healing of Experimental Syphilis Lesions in Rabbits by Short Wave Diathermy J Exp Med 56 751 1932

"It is evident that the increased heat of the fever provides an unfavorable environment for the spirochetes that either destroys or injures them so that they lose their infectivity We do not know whether in syphilis, the elevated temperature also stimulates, or activates those factors in the body that are concerned with its protection against infection However, in studies on gonorrhea we have observed increased phagocytosis during artificially induced fever. This leads us to believe that such factors may play a prominent part in syphilis"

Jung[184] made several hundred determinations of erythrocyte counts, complement titer, opsonic index, phagocytic power of leucocytes, and agglutinations on seventeen patients subjected to artificial fever for various diseases, and found the only significant immunologic change produced was a temporary increase in the leucocytic count immediately after hyperpyrexia The alterations in complement content, opsonins, and the phagocytic property of leucocytes were found to be within the limits of normal variation

Neymann, Lawless, and Osborne,[185] treating patients suffering with early syphilis, stated that positive, or more intensely positive, serologic reactions developed after the first fever treatment They believed it safe to conclude that there is a rapid and intense mobilization of antibodies following fever therapy They theorized that this was due to a massive destruction of the spirochetes, but realized that other factors may play an important role in bringing about this increase in amboceptor formation In the five biopsies made, they found spirochetes still present in the inguinal lymph glands after treatment, Figs 235 and 236, while the chancre or original site of infection showed no organisms The spirochetes in the lymph glands were somewhat atypical, and did not produce syphilomas when transplanted into the testicles of a rabbit Figs 237 and 238, before and after, show the effect of fever on the spirochetes in the chancre itself They concluded that not all the spirochetes, especially those found in the lymph glands, are destroyed by heat alone The experiments that fix the *in vitro* death point of

[184] Jung, R. W Immunologic Studies in Hyperpyrexia. Arch Phy Therap 16 397 1935

[185] Neymann, C A. Lawless, J K, and Osborne S L. The Treatment of Early Syphilis with Electropyrexia J A.M.A 107 194 1936

spirochetes at 41° C maintained for two hours, or 42° C maintained for one hour, therefore, do not apply to spirochetes found in the living human body

Ecker and O'Neal[186] induced hyperpyrexia in rabbits and guinea pigs of 40° to 43 1° C They immunized the rabbits and guinea pigs to bacillus typhosus and reported a depression of agglutinins during the time of fever The antibody titer, however, soon returned to normal The guinea pigs all showed a decrease in complement, although the complement was not completely destroyed

Reimann[187] showed that an increase in plasma viscosity, depending on an increase in the fibrinogen and globulin fractions of the blood, enhances specific agglutination, and suggested that these protein changes which occur during infectious diseases play an important role in immune processes In a later study on lobar pneumonia, Moen and Reimann[188] found a prompt increase in the plasma globulin and fibrinogen fractions, together with increased plasma viscosity, within a short while after the chill It seems possible that the high fever associated with the disease, together with the severe toxemia, may have been an important factor in inducing these blood protein changes Since then Moen, Medes, and Chalek,[189] using diathermy to produce hyperpyrexia in dogs, came to the conclusion that fever alone is not an important factor in evoking the plasma changes usually observed in infectious diseases The observations made by Osborne, Markson, Driscoll, and Merriman[190] on arthritic patients indicate that temperature *per se* has no influence on the total serum proteins Their measurements are within normal variations Table 72

[186] Ecker, E E and O Neal The Effect of Hyperpyrexia Induced by Ultra High Frequency Current on B Typhosus Agglutinin and Complement Am. J Pub Health *22* 1050 1932

[187] Reimann, H A Significance of Fever and Blood Protein Changes in Regard to Defense Against Infection, Am. Int. Med *6* 362 1932

[188] Moen, J K and Reimann H A. Plasma Protein Changes and Suspension Stability of the Blood in Lobar Pneumonia J Clin. Invest. 12 589 1933

[189] Moen, J K., Medes G and Chalek, I The Relative Effects of Diathermy and Infection on the Plasma Proteins, Plasma Viscosity, and Suspension Stability of the Blood in Dogs J Lab & Clin Med. 19 571 1934

[190] Osborne, S L, Markson, D E., Driscoll, R E., and Merriman, J R. Treatment of Arthritis by Electropyrexia J Lab & Clin Med. 27 1135 1942

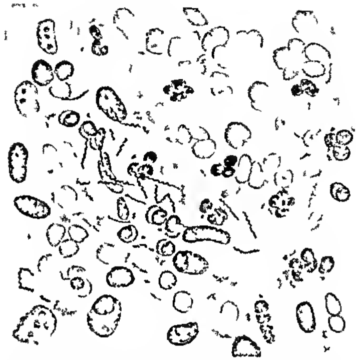

Fig 237 Spirochetes in a histologic section of a chancre before treatment (From Neymann Lawless and Osborne J A.M A 107 194 1936)

Carpenter, Boak, Mucci, and Warren,[191] from their study of patients infected with gonorrhea concluded that it was evident some injury, other than that due to heating, occurs to the gono coccus, making it more susceptible to destruction by the normal defenses of the body Clinically, they observed cures' resulting from such fevers as 41 5° C maintained for five hours, whereas they were unable to destroy these organisms *in vitro* by a similar exposure

Hodjopoulos and Bierman[192] subjected rabbits to a temperature

[191] Carpenter C M Boak R. A. Mucci L A. and Warren S L. Studies on the Physiologic Effects of Fever Temps J Lab & Clin. Med 18 981 1933

[192] Hodjopoulos G and Bierman W Effects of Hyperpyrexia Induced by Physical Means Upon Complement fixing Antibodies J Lab & Clin Med 20 227 1934

FIG 238. Absence of all spirochetes in the histologic section of the site of the chancre after two hyperpyrexia treatments Temperature above 105 8° for four and one half hours, and above 107 6° F for one hour. (From Neymann, Lawless, and Osborne. J A M A. 107:194:1936.)

of 41° to 42° C. for 3 to 4 hours. They reported a temporary diminution of complement-fixing antibody titer when their animals were immunized against staphylococci, streptococci, micrococci catarrhalis, and diphtheroid bacilli. They stated they also found a delayed stimulation phase in the daily antibody titers.

Wulff[193] demonstrated, in 85 per cent of his patients, a thermostabile bacterial substance in human serum during the febrile period of infectious fevers. In 90 per cent of non-febrile patients

[193] Wulff, F.: On Thermostabile Bactericidal Substance Demonstrated in Human Serum Particularly During Fever. J. Immun. 27:451:1934.

this substance could not be demonstrated The injection of sulfosin also appeared to stimulate organisms to produce a thermostabile bacterial substance. His experiments showed, further, that this bactericidal substance possessed enzymic properties.

Tillett[194] points out that the extracts of leucocytes (leukin) have

TABLE 72

EFFECT OF HYPERPYREXIA ON BLOOD PROTEIN ANALYSIS (26 DETERMINATIONS)

	Range		Average
	Maximum	Minimum	
Total blood proteins	9 2	6 02	7 37
Albumin	7 0	3 73	4 76
Globulin	4 7	1 02	2 53
Fibrinogen	0 82	0 17	0 42
A/G ratio	5 2	0 84	1 9

been found to be bactericidal, and has led some investigators to offer the suggestion that the bactericidin of serum may be derived from leucocytes. However, he noted several exceptions He found cases with normal or leucopenic white blood cell count but with serum markedly effective in streptococcidal activity. He further noted a relatively close parallelism between the bactericidal capacity of the serum and the temperature of the patient. He postulated that it would be of great interest to attempt to determine whether fever *per se* is of primary importance in influencing changes in the blood serum, or whether other factors inherent in active febrile disease cause the appearance and disappearance of the humoral bactericidal property.

Rich and McKee[195] reported that rabbits inoculated with type III pneumococcus acquire a greatly enhanced resistance to further infection within twenty-four hours. They showed this resistance

[194] Tillett, W. S: The Bactericidal Action of Human Serum on Hemolytic Streptococci J Exp Med 65 147 1937

[195] Rich, A. R, and McKee, C Native Immunity to Type III Pneumococcus. Johns Hopkins Hosp Bull 59 171:1936

was not due to acquired immunity but to the fever that develops as a result of the infection.

Benedict[196] stated that when heat is produced generally, as in fever, there is in addition to its local action, a physiologic factor that makes available certain non-specific antibodies, which in themselves probably exert a favorable influence.

According to Doan[197] the rather constant hemopoietic response to fever may be non-specific and is by no means necessarily the most important from the standpoint of the fundamental body defenses. He further stated that the hemograms following malaria and B-typhosus inoculation, differs from those observed during fever induced by physical methods In infectious fevers the hemogram shows a marked leucopenia during the chill, a temporary disappearance of the monocytes following typhoid, and a moderate stimulation of the monocytes following typhoid vaccine. The shift to the left in the neutrophilic granulocytes in malaria is outstanding, and the appearance of clasmatocytes in the peripheral blood has been observed in no other type of fever. While physically induced fever does not show an increase in clasmatocytes, Doan calls attention to the tremendous increase in these phagocytic cells elsewhere in the tissues, more especially in lymph nodes, spleen, and liver. He believes that artificial fever by physical means not only provides the thermal factor of importance for the inactivation of the treponema pallidum and the gonococcus, but also affects profoundly the mobilization of the defense forces of the body against such infections.

Moench[198] performed a series of *in vitro* experiments to ascertain the effect of heat on the growth of meningococcus. She was interested in studying the effects of the temperatures generally used in hyperpyrexia. Fifteen strains of meningococci were subjected to

[196] Benedict, W. H.: Discussion of paper by Culler, C H, and Simpson, W M Artificial Fever in Cases of Ocular Syphilis Arch Ophthal 15 624 1936

[197] Doan, C A.: Peripheral Blood Phenomenon and Differential Response of Bone Marrow and Lymph Nodes to Hyperpyrexia. Radiology 30 382 1938

[198] Moench, L M A Study of the Heat Sensitivity of the Meningococcus in Vitro Within the Range of Therapeutic Temperatures, J Lab & Clin Med. 22 665.1937.

temperatures which ranged from 40° to 42° C and which were maintained from three to seven hours All strains, with a few exceptions, were either destroyed or their growth reduced. Some strains were consistently destroyed at lower temperatures and with shorter exposures than others. According to this investigator, the experiments indicated that a temperature of 41 6° C, maintained for at least five hours, should be of clinical value. Moreover, Moench thought it might be possible that hyperpyrexia would hasten the absorption of meningeal exudate and so prevent the development of adhesions and the resultant block to the circulation of cerebrospinal fluid.

Shaffer, Enders, and Wilson,[199] from previous studies,[200, 201] believed that the results of their experiments suggested possible modes of attack upon infections caused by type III pneumococcus meningitis in man. They accordingly treated two patients suffering from pneumococcus type III with artificial fever alone; two patients with rabbit serum of high specific-antibody titer, mixed together with human complement, which was injected intrathecally; and one patient to whom both treatments were administered simultaneously. The patients given artificial fever had their temperatures elevated to 105° to 107° F. for five to ten hours. They determined at intervals the effect of these various procedures on the bactericidal population and on the fluctuations in content of soluble specific precipitable antigen, as well as on free antibody when this was injected. Hyperpyrexia alone produced a marked reduction in the number of viable pneumococci and the quantity of free soluble type-specific antigen present. But in neither patient was sterility of the fluid attained. The combined treatment of hyperpyrexia and injection of rabbit antiserum appeared to produce best results as estimated by the conditions obtaining in the cerebrospinal fluid

[199] Shaffer, M F., Enders, J. F, and Wilson, J · The Effect of Artificial Fever and Specific Antiserum on the Organisms Present in Cases of Type III Pneumococcus Meningitis, J. Clin Invest. 17 138. 1938

[200] Enders, J F., and Shaffer, H E · Studies on Natural Immunity to Pneumococcus Type III, J. Exp Med. 64 7·1936

[201] Enders, J F, and Shaffer, M F: An Analysis of Certain Factors in the Virulence for Rabbits of Pneumococci Type III, J Immunol 30 382 1936

None of the five patients treated recovered from the infection

From the foregoing discussion, it is quite evident that the effect of hyperpyrexia on immunologic reactions is not completely understood

VII The Use of Sedatives It is unfortunate that a serious investigation of the use of sedatives in therapeutic hyperpyrexia has not been made It is our opinion that too frequently drugs are used without discrimination and undoubtedly have in some instances caused or precipitated a major crisis Most of the sedatives used are respiratory depressants, and, as Hartman[202] points out in discussing the pathological findings of both experimental animals and patients which he studied at autopsy, it seems justifiable to place anoxemia as the underlying cause of the lesions, and the sedatives used in conjunction with artificial fever as the initiating or predisposing cause of the anoxemia All investigators agree that cerebral edema is a constant effect of anoxia on the brain This then might account for the varying degrees of delirium reported by investigators Landis,[203] by demonstrating that fluid passes through capillary walls at four times the normal rate after only three minutes lack of oxygen, furnished the probable explanation Jewett and Quastel[204] demonstrated that phenobarbital decreases or abolishes oxygen utilization by the brain Hartman[205] reported that the administration of oxygen tended to reduce the sedative effect of sodium amytal (sodium amytal with other sedatives apparently affects the cells directly), decreasing the utilization of oxygen, and thus having a selective action on the brain

Dowdy and Hartman[206] stated that cyanosis and anoxemia are

[202] *Hartman F W Lesion of Brain Following Fever Therapy Etiology and* Pathogenesis J A M A 109 2116 1937

[203] Landis E. M Micro *Injection* Studies of Capillary Permeability of the Capillary Wall to Fluid and to the Plasma Proteins Am J Physiol *83 528 1938*

[204] Jewett M and Quastel J H The Effects of Narcotics on Tissue Oxidations Biochem J 31 565 1937

[205] Hartman F W Lesion of Brain Following Fever Therapy Etiology and Pathogenesis J.A.M.A 109 2116 1937

[206] Dowdy A. H and Hartman F W Preparation of Patients for Fever

not synonymous terms but are frequently coexisting conditions Strong barbiturates are respiratory depressants, and cyanosis in a marked degree is frequently noted during fever therapy when these drugs are used They also stated that depth and duration of sedation are fundamental problems in hyperpyrexia Deep anesthesia establishes factors conducive to anoxemia with resultant injury to brain tissue. Dowdy and Hartman stated that they found sedormid to be a weaker drug with a greater margin of safety than the barbiturates, and, hence, recommended its use.

As a result of their experiments, Neymann and Osborne[207] no longer use hyoscine, but morphine sulfate alone. Any drug that inhibits sweat in a marked manner, they believed to be contraindicated. Atropine is such a drug, and certainly any theoretically beneficial action this drug may possess by increasing the heart action, is outweighed by its effects on the sweat glands

Other drugs such as adrenalin and compounds related to it, constrict the peripheral blood vessels, and therefore, are likely to cause a rise in body temperature of the patient, as well as an increase in heart rate.

Strychnine increases the activity of the striated muscles by rendering the reflex arcs of the spinal cord more excitable It may produce convulsions in susceptible patients. A convulsion causes an immediate and unpredictable rise in temperature.

In cases of emergency, such as shock, digitalis is considered to be contraindicated, chiefly because, according to Warfield,[208] it decreases blood volume. There already exists a decrease in blood volume during hyperpyrexia according to Gibson and Kopp[209] On the other hand, caffein sodiobenzoate can be safely used, and has a tendency to increase blood volume according to Warfield[208]

One concludes that sedatives should and can be used much less

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Therapy with Special Reference to Sedation and Fluid Intake Abst and Discuss First Int Fever Conf p 50, Paul B Hoeber, Inc Philadelphia, 1937

[207] Neymann, C A, and Osborne, S L The Physiology of Electropyrexia, Am J Syp & Neurol 18 28 1934

[208] Warfield, L M The Treatment of Circulatory Failure, Ann Int Med 7 981.1934

[209] Gibson, J G, and Kopp, I · Studies in the Physiology of Artificial Fever

frequently than has been the case Moreover, there should be a more judicious choice of the sedative to be used when one is necessary

VIII THE EFFECT OF HYPERPYREXIA ON THE SECRETION AND FLOW OF BILE Sorokin[210] found, by using hot mud over the region of the liver, that the flow of bile into the duodenum was at first decreased but later increased

Koza,[211] using local diathermy to the liver, found that a twenty minute treatment, repeated two or three times during the filling of the gallbladder, accelerated the filling time Similar results were reported by Rouzard and Aimard,[212] and more recently con firmed by Rafsky [213]

Frisch and Lasch[214] stated that the normal individual showed an increase in the secretion and concentration of bile during and after diathermy

Goldgruber[215] reported an increase in bile flow as observed by means of a duodenal tube

Couperus and Moore[216] applied local diathermy to the liver of trained chronic biliary fistula dogs, and reported an increase in the bile volume output of eight to forty six per cent in the first twelve hour period after treatment The total twenty four hour bile volume output was increased seven to seventeen per cent,

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I Changes in the Blood Volume and Water Balance J Clin Invest 17 219 1938

[210] Sorokin C E Action of Locally Appl ed Heat on Propulsion of Bile Secreting Into Duodenum Klin. Med 5 296 1927

[211] Koza F Liver Diathermy and Its New Use in Cholecystography Casop lek cesk. 67 601 1928.

[212] Rouzaud J J and Aimard J La Diathermie. Sa Valeur Dans le Traitment des Lithiasiques Biliares Presse Med 31 47 1923

[213] Rafsky Henry A Diathermy and Biliary Tract Disease Arch Phys Ther 18 214 1937

[214] Frisch A V and Lasch F Zur Funktionsprufung de Leber Acta Med Scand. 69 241 1928

[215] Goldgruber Geza Uber de Diathermie Behandlung der Leberkrankheiten Klin Wchnschr 11 286 1932

[216] Couperus M and Moore F B The Effect of Diathermy Upon the Secretion of Bile Arch Phy Ther 15 5 1934

they reported Unfortunately, however, they recorded only one twenty four hour control period before the application of heat They stated that previous work of other investigators convinced them that the total twenty four hour bile volume output varies but little under standard conditions, and hence they did not consider it necessary to record a longer control period However, long observation on biliary fistula dogs on a standard regimen has shown[217, 218] considerable daily variation in volume This amounts to ± eight per cent when the suction method is used and may be as high as ± twenty per cent when the bag technique is employed Hence, we feel that the seven to seventeen per cent increase reported may well have been within the normal variation of the animal Another objection is the fact that these workers left the gall bladder in place, draining the bile by means of a tube in the fundus This introduces an uncontrollable factor namely, variations in concentrating activity of the gall bladder

Karapetyan[219] noted that the local application of diathermy over the liver caused an augmentation of bile flow, and increased the amount of bile constituents in Pavlov biliary fistula dogs

He reported an increased bile flow of 54 4 per cent However the report does not make clear whether his dogs were standardized in regard to daily output before the heating period Schwiegh[220] showed an increased blood flow in the hepatic artery by means of the Rein thermostromuhr following the administration of heat applications to the liver and the intravenous injection of decholin Tanturi and Ivy[221] have shown that reflexly increasing the intra

[217] Kocour E J and Ivy A C The Effect of Certain Foods on Bile Volume Output Recorded in the Dog by a Quantitative Method Am J Physiol *122 325 1938*

[218] Schmidt C. R. Beazell J M Berman A L Ivy A C and Atkinson A J Studies in the Secretion of Bile Am J Physiol *126 120 1939*

[219] Karapetyan O K The Effect of Diathermy on Bile Formation Ztschr f d g Physiol Terapie *43 H6 1932*

[220] Schwiegh H Untersuchungen Über die Leberdurchblutung und den Pfortaderkreislauf Arch fur Experim Path und Pharmak *168 693 1932*

[221] Tanturi A and Ivy A C A Study of the Effects of the Vascular Changes in the Liver and the Excitation of its Nerve Supply on the Formation of Bile Am. J Physiol *121 61 1938*

hepatic vascular pressure by stimulating the splanchnic nerves, chologenesis is inhibited and that sectioning the hepatic nerves diminishes the intrahepatic vascular pressure and accelerates bile flow It might be assumed, then, that providing the blood pressure is not depressed, fever causes an increased blood flow through the liver, which may stimulate bile formation by augmenting the metabolism of the liver cells

The results of acute animal experiments by Osborne, Grodins and Ivy[222] showed a definite choleretic effect. Each experiment continued over a period of many hours The animals were under an anesthetic, which depressed the respiratory center so that the animals did not pant until a temperature of 41 5° C. was attained The panting period did not exceed one-half hour. Hemingway[223] has shown that unanesthetized dogs begin to pant when their temperature is elevated only slightly

Although heat produced a hydrocholeresis in the acute experiments, the increased volume flow more than offset the diminished concentration of the biliary constituents In the control group, although the volume flow did not always diminish, the total gravimetric output of solids usually did

Their chronic biliary fistula dogs showed no such choleretic effect They were somewhat at a loss to explain this discrepancy between the acute and chronic experiments The dogs were unanesthetized during the chronic experiments Even well-trained dogs become excited and restless when their rectal temperature is rapidly raised to 106° to 107° F As a result, there probably occurs a hyperactivity of the sympathetic or adrenal mechanism with a generalized sympathetic stimulation. It has been shown[224] that stimulation of the hepatic sympathetic nerves causes a de-

[222] Osborne, S L., Grodins, F S, Goldman, L, and Ivy, A C Effect of Hyperpyrexia on Secretion and Flow of Bile, Am J Physiol 132 32-41, 1941

[223] Hemingway, Allen The Panting Response of Normal Unanesthetized Dogs to Measured Doses of Diathermy Heat, Am. J Physiol 121 747 1938

[224] Tanturi, A, and Ivy, A. C A Study of the Effects of the Vascular Changes in the Liver and the Excitation of its Nerve Supply on the Formation of Bile, Am. J Physiol 121 61 1938

crease in bile secretion This may explain, in part, these contradictory results Moreover, several hours elapsed before the animals recuperated from the generalized depression which resulted from the treatment.

Gibson and Kopp[225] have shown that with external heating devices such as were used, the blood volume shows a very marked decrease, but that if sweating does not take place the blood volume does not change An analogous condition exists between the two kinds of experiments The dogs in the acute experiments panted very little and but for a few minutes (analogous to sweating), while the chronic dogs panted and drooled at the mouth all through the experiment. The work of Reinhold and Wilson[226] indicates that hydremia may produce choleresis Conversely then, a decreased blood volume may result in a decreased bile volume output. They stated that in anesthetized dogs, application of heat over the liver promoted bile flow, but provided no evidence in support of their observation

It is not altogether unlikely that blood pressure was decreased as a result of the treatment, and as Osborne, Grodins, Goldman, and Ivy[227] pointed out, this could be a factor in decreasing the volume output.

They also stated that they were not positive that they had accurately evaluated the changes found, because of the large spontaneous daily variation in the dogs Ordinarily, in the experiments on biliary fistula dogs, a control is taken which represents the average of several days observation This is then compared to an average for the treated dogs taken over a similar number of days When average values of this type are compared, spontaneous daily variations tend to be cancelled In the experiments referred to, a control was taken in the manner just described, but it was compared to the value for only one day, namely, the

[225] Gibson, J G, and Kopp, I Studies in the Physiology of Artificial Fever I Changes in the Blood Volume and Water Balance, J Clin Invest. 17 219 1938

[226] Reinhold, J G, and Wilson, D W The Determination of Chloric Acid in Bile, J Biol Chem 96 637 1932

[227] Osborne, S L, Grodins, F S, Goldman, L, and Ivy, A. C Effect of Hyperpyrexia on Secretion and Flow of Bile, Am. J Physiol 132 32 1941

day of treatment. The nature of the experiments made it impossible to give daily treatment. In this type of comparison, the part contributed by spontaneous variation is far more difficult to evaluate.

In Fig 239 the results obtained in an acute experiment are shown.

IX. MISCELLANEOUS RESPONSES TO FEVER *Capillary Resistance.* Rossman[228] in an attempt to explain the mechanism of hemorrhage in artificially induced fever, made studies of capillary resistance by means of the suction test on 12 subjects, three of whom were used twice, making a total of 15 observations The outstanding pathologic observations in experimental animals and human subjects following induced fever have been the presence at autopsy of focal hemorrhages and acute parenchymatous degeneration of the organs.

Rossman observed that induced fever by means of the Kettering Hypertherm produced an immediate decrease in capillary resistance as determined by the suction test applied to the skin of the forearm There occurred a quick return of the skin capillaries to normal resistance, with a temporary hyper-resistance in many instances, following such a treatment. The focal hemorrhages seen at autopsy after artificially induced fever in experimental and clinical subjects may be due to decreased capillary resistance

The author was unable to determine the exact cause of this decreased capillary resistance, but regards vasodilatation and increased intracapillary pressure as the probable underlying factors.

Effect of Hyperpyrexia on Spermatogenesis. Moore[229] has presented in a series of papers abundant evidence to show that

[228] Rossman, Philip L Capillary Resistance in Artificially Induced Fever Ann Int Med 14 281·1940

[229] Moore, C R, and Oslund, R. Experiments on Sheep Testes, Cryptorchidism, Vasectomy Scrotal Insulation Am J Physiol 67 595 1924

Moore, C R, and Quick, W J Scrotum as Temperature Regulator for Testes Am J Physiol 68 70 1924

Moore, C R Properties of Gonads as Controllers of Somatic and Psychial Characteristics Heat Application and Testicular Degeneration, Function of Scrotum. Am J Anat. 34 337 1924

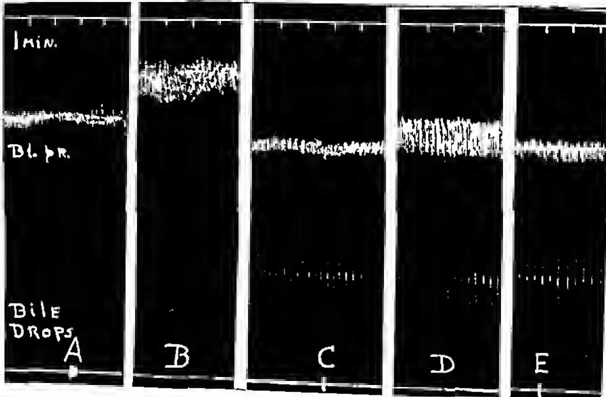

FIG 239 Effect of hyperpyrexia on bile flow (acute experiment) A Control period B Temperature 41 5° C C Temperature 39 0° C three hours later than B D Two hours after C E Finish of experiment ten hours after control period (From Osborne Grodins Goldman and Ivy Am J Physiol 132 32 1941)

exposure of the testes of the rat, guinea pig, and sheep to temperatures above that of the scrotum results in degeneration of the germinal epithelium, and a consequent failure of spermatogenesis. The effect of high temperature on spermatogenesis seems general for all mammals, but similar experiments on man were not reported until MacLeod and Hotchkiss[230] published their findings in 1941. They used six healthy young unmarried donors The body temperature of the subjects was elevated and ranged from 104° F. to 105 8° F. The cabinet temperature was maintained at 110° F. After a control count was secured and treatment given, total spermatozoa counts were taken at intervals of three to six days In every case, they state, it was evident that shortly after the initial fever treatment, the total sperm counts began to fall, reaching distinctly low levels at intervals ranging from 25 to 55 days after treatment. This low level was maintained for periods ranging from fifteen to fifty days, after which the counts show a relatively rapid rise.

The question of the possible injury to male or female gonads by fevers ranging up to 42° C. (107 6° F.) was answered by the researches of Knudson and Schaible,[231] who found that the growth and reproduction of the white rat was not impaired by repeated exposures to sublethal doses of high frequency radio waves. Boak, Carpenter and Warren[232] later ascertained the same facts using white rabbits as experimental animals They conclude that the repeated elevation of the body temperature by short radio waves is innocuous to the functioning of the reproductive organs Neymann, in his book on artificial fever,[233] states:

[230] MacLeod, J, and Hotchkiss, R S · Effect of Hyperpyrexia on Spermatozoa Counts in Men Endocrinology 28 780 1941

[231] Knudson, A, and Schaible, P J · Physiologic and Biochemical Changes Resulting from Exposure to an Ultra high Frequency Field on Growth and on *Reproduction in White Rats Arch Path 11 725* 1931

[232] Boak, R A, Carpenter, C M, and Warren, S L Studies on the Physiological Effects of Fever Temperatures 3 J Exper Med 56 731. and 725 1932

[233] *Neymann, C A Artificial Fever Charles C Thomas, Publisher, Springfield, Ill* 1938

"Two of my patients have given birth to healthy children within a year after completion of a series of twenty artificial fever treatments produced by electro-magnetic waves During each treatment, a fever ranging above 40 6° C (105° F) was maintained for eight hours Two male patients showed no decrease in the number or the motility of their spermatozoa forty-eight hours after treatment with temperatures ranging near 42° C. (107 6° F.). The wife of another male patient became pregnant while the patient was being treated ambulantly. In this case there would seem to be no question of the paternity of the child, although I realize that the careful investigator might raise this issue. Several other male patients have noted an increase in potency and libido during the period of treatment and directly following it Hoctor[234] while discussing one of my recent papers, stated that he treated a female with electromagnetically induced fever, who was afflicted with dementia paralytica This woman was in the sixth month of pregnancy and gave birth to a healthy male child two months later.

"Artificial fever produced in man by means of physical agents for the length of time and the height of temperature usually used for this purpose does not injure or harm the functioning of the reproductive organs "

Effect of Body Temperature on Pancreatic Secretion Osborne and Greengard[235] investigated the effect of temperature on pancreatic secretion They artificially lowered and raised the temperature of six dogs Hyperpyrexia was secured by means of induction heating and the rectal temperature of their animals was elevated to a level of 41° C. to 42° C. (105 8° F. to 107 6° F) They reported that in all six of the dogs in which the temperature was raised there was an increased output of pancreatic secretion ranging from about 50 to 700 per cent. Fig 240 It was found that the rate of increase depended on the control rate of flow and was most marked when this was slow When the high fre-

[234] Neymann, C A. The Effect of Artificial Fever on the Clinical Manifestations of Syphilis and the Treponema Pallidum. Am J Psychiat 93 938 1936

[235] Osborne, S L, and Greengard, H Effect of Body Temperature on Pancreatic Secretion Proc Am Physiol Soc p 216 1941

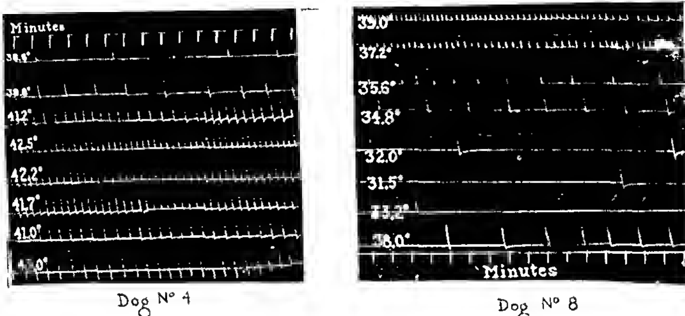

Fig 240 Kymographic records of rate of pancreatic secretion in drops per minute Rate changed with change in body temperature Initial temperatures Dog No 4 38 6° Dog No 8 38° C Temperature was increased in Dog No 4 and decreased in Dog No 8

quency current was turned off and the animal permitted to cool, the effect of the hyperpyrexia persisted in that the secretory rate did not increase to the same extent as it had increased when the temperature was raised, and when the temperature had returned to normal, the secretory rate was definitely more rapid than the original control flow. These investigators stated that undoubtedly the mechanism whereby such secretory alterations are produced is vascular in nature. The hyperpyrexia was attended by a moderate rise in blood pressure and a marked visible engorgement of the blood vessels of the abdominal viscera Thus it is apparent that there is a markedly increased supply of secretion to the pancreas through its increased supply of blood

APPENDIX A

LOGARITHMS

Logarithmic System of Notation.

In the common system of notation, numbers are expressed as multiples of the powers of 10 For example, 5296 means 5 times 10^3, plus 2 times 10^2, plus 9 times 10^1, plus 6 times 10^0. Should the number consist also of a fraction, as 5296 723, the number consists of those multiples of the powers of 10 already given, plus 7 times 10^{-1}, plus 2 times 10^{-2}, plus 3 times 10^{-3}.

In the common system of notation, a number is represented by a series of different powers of ten, the exponent of each power being integral. By the use of fractional exponents, however, any number may be represented, approximately, as a single power of ten.

The Logarithm of a Number·

When a number is expressed in this way, *i.e.* as a power of 10, the exponent of 10 is called the *logarithm to the base 10* of the number. For brevity, *logarithm* is written *log* If the base of the logarithm is some number other than 10, that fact is indicated by writing the number as a subscript. For example, the logarithm to the base e of the number M is written $log_e M$. If no subscript is used, it is understood that 10 is the base of the logarithm.

The logarithms to the base ten of numbers between

1	and	10	is	0 + a fraction
10	and	100	is	1 + a fraction
100	and	1000	is	2 + a fraction
1000	and	10000	is	3 + a fraction
1	and	0.1	is	− 1 + a fraction
0.1	and	0.01	is	− 2 + a fraction
0.01	and	0 001	is	− 3 + a fraction

From the foregoing we see that the logarithm of a number consists of two parts, an integral part and a fractional part. The integral part is called the *characteristic;* and the fractional part, the *mantissa.*

The Characteristic.

The characteristic of the logarithm of an *integral number*, or of a *mixed number, is positive and one less than the number of integral digits.* Thus, logarithms of all numbers from 0 to 10 have as a characteristic 0; 10 to 100, 1; 100 to 1000, 2; etc

The characteristic of the logarithm of a decimal fraction is negative, and is equal to the number of the place occupied by the first significant figure of the decimal. Thus, logarithms of all numbers from 0 1 to 1.0 have as a characteristic, -1; 0 01 to 0.1, -2; 0 001 to 0 01, -3; etc.

The Mantissa:

The *mantissa* is always made positive. The logarithms of numbers less than 1 are therefore made to consist of a negative characteristic and a positive mantissa, the resulting logarithm, if the algebraic addition is performed, being negative. It is customary to write a minus sign over the characteristic of the logarithm of a number less than one to indicate that it is only the characteristic that is negative—or to add 10 to the characteristic and to indicate the subtraction of 10 from the resulting logarithm. For example·

$$\log 0.2 = \bar{1}.30103 = 9.30103 - 10.$$

By performing the indicated algebraic addition, we obtain $\log 0\ 2 = -0.69897$, a form more convenient for such procedures as the finding of roots or the raising to powers. It must always be remembered, however, that the mantissas given in a table of logarithms are positive and therefore conversion of the logarithm to a form in which the fractional part is positive must be made before using such tables to find the number corresponding to the logarithm.

The mantissa of the logarithm of any integral number, mixed number, or decimal fraction depends only upon the digits of the number, and is unchanged so long as the sequence of the digits is unchanged. Obviously, changing the position of the decimal point of a number is equivalent to multiplying or dividing by a power of 10. The logarithm of the number, therefore, will be increased or decreased by the exponent of that power of 10.

Since this exponent is integral, the characteristic alone of the logarithm will be affected, the mantissa remaining unchanged For example

$$
\begin{aligned}
\log\ .002 &= \log (2 \times 10^{-3}) = \bar{3}.30103 \\
\log\ .02 &= \log (2 \times 10^{-2}) = \bar{2}.30103 \\
\log\ .2 &= \log (2 \times 10^{-1}) = \bar{1}.30103 \\
\log\ 2 &= \log (2 \times 10^{0}) = 0.30103 \\
\log\ 20 &= \log (2 \times 10^{1}) = 1.30103 \\
\log\ 200 &= \log (2 \times 10^{2}) = 2.30103 \\
\log\ 2000 &= \log (2 \times 10^{3}) = 3.30103 \\
\log\ 20000 &= \log (2 \times 10^{4}) = 4.30103
\end{aligned}
$$

Logarithms to Any Base

Other numbers than 10 can of course be used as the base of a system of logarithms The advantage, however, of using 10 as the base consists in the fact that the *mantissa* depends only on the *sequence of digits*, and the *characteristic* on the *position of the decimal point*

To convert the logarithm of a number from one base to another, apply the following relation

$$\log_b N = \frac{\log_a N}{\log_a b}$$

A number frequently occurring in the mathematical relations of science is the irrational number designated by the letter e Its numerical value is the summation of a particular mathematical series and can be computed to be approximately 2.7182818 It is convenient at times to express the logarithms of numbers to this base Let us assume we have available a table of logarithms to the base 10 The foregoing relation can be written

$$\log_e N = \frac{\log_{10} N}{\log_{10} e} = 2.302585 \log_{10} N$$

Should the logarithm of a quantity to the base e be given, its logarithm to the base 10 can be readily found as follows

$$
\begin{aligned}
\log_{10} N &= \log_{10} e \log_e N \\
&= 0.4343 \log_e N
\end{aligned}
$$

Operations with Logarithms·

Logarithms are simply exponents, therefore,

The logarithm of a product of two or more numbers is the sum of the logarithms of the factors. Thus,

$$\log (N \times M) = \log N + \log M.$$

The logarithm of a quotient is equal to the logarithm of the dividend minus the logarithm of the divisor. Thus,

$$\log (N \div M) = \log N - \log M.$$

The logarithm of a power of a number is equal to the logarithm of the number multiplied by the exponent of the power. Thus,

$$\log (N^a) = a \log N.$$

The logarithm of the root of a number is equal to the logarithm of the number divided by the index of the root. Thus,

$$\log \sqrt[a]{N} = \log (N^{1/a}) = 1/a \log N.$$

Finding the Logarithm of a Number:

1. Let 3467.3 be the number.

   (a) Since it is greater than 1, the characteristic of its logarithm is positive.

   (b) Since there are 4 integral digits, the numerical value of the characteristic is 3.

   (c) Since the value of the mantissa is affected only by the sequence of digits, we can forget the position of the decimal point after having determined the characteristic and proceed as if the number were 346.73 This number lies between 346 and 347, being located at a point 0 73 units above 346 or 0.73 of the difference between 346 and 347.

   (d) Its mantissa is therefore found by taking the mantissa of 346 and adding to it 0.73 times the difference between the mantissa of 347 and that of 346. Its logarithm is therefore log 3460+0 73 (log 3470−log 3460) or 3 9050 The procedure is as follows:

$$
\begin{array}{ll}
\log 3470\ 0 & = 3\ 5403 \\
\log 3460\ 0 & = \underline{3\ 5391} \\
\log 3470 - \log 3460 & = 0\ 5012 \\
\dfrac{3467\ 3 - 3460\ 0}{3470\ 0 - 3460\ 0} & = 0\ 73 \\
0\ 73 \times 0\ 5012 & = 0\ 3659 \\
\log 3460\ 0 & = \underline{3\ 5391} \\
\log 3467\ 3 & = 3\ 9050
\end{array}
$$

2 Let 0 06732 be the number

(a) Since it is less than 1, the characteristic of its logarithm is negative

(b) Since the *first significant figure* occupies the *second* place to the right of the decimal, the numerical value of the characteristic is 2, but negative as already pointed out

(c) Since, in finding the mantissa, we are interested only in the sequence of digits, we can forget the position of the decimal *after having determined the characteristic* and proceed as if the number were 673 2 This number lies between 673 0 and 674 0, being located at a point 0 2 units above 673 0 or 0 2 of the difference between 673 0 and 674 0

(d) Its logarithm is therefore log 0 06732 plus 0 2 times (log 0 06740 − log 0 06730) or 8 82814 − 10 The procedure is as follows

$$
\begin{array}{lll}
\log 0\ 06740 = \bar{2}\ 8287 & & = 8\ 8287 - 10 \\
\log 0\ 06730 = \bar{2}\ 8280 & & = \underline{8\ 8280 - 10} \\
\log 0\ 06740 - \log 0\ 06730 & & = 0\ 0007
\end{array}
$$

$$
\begin{array}{ll}
\dfrac{0\ 06732 - 0\ 06730}{0\ 06740 - 0\ 06730} & = 0\ 2 \\
0\ 2 \times 0\ 0007 & = 0\ 00014 \\
\log 0\ 06730 & = \underline{8\ 82800 - 10} \\
\log 0\ 06732 & = 8\ 82814 - 10
\end{array}
$$

*Finding the Number **Corresponding** to a Logarithm, or the Antilogarithm:*

1. Let 2.6732 be the logarithm of a number
   (a) Since the characteristic is positive, the number is greater than 1.
   (b) Since the characteristic has the numerical value of 2, the number of integral digits is 3.
   (c) The purpose of the characteristic is to determine the position of the decimal point; so, having done that, we consider only the mantissa of the given logarithm to determine the sequence of digits which constitute the number. From the table we find that the mantissa 6732 lies between the mantissas 6730 and 6739, being $2 \div 9$ or 0 22 of the difference greater than 6730.
   (d) The number lies therefore between that whose logarithm has a mantissa of 6730 and that with a mantissa of 6739, these numbers being respectively 471 and 472 The antilogarithm of 2.6732 is therefore the antilog 2 6730 plus 0 22 (antilog 2 6739 $-$antilog 2 6730) or 471 22. The procedure is as follows:

$$\begin{aligned}
\text{antilog } 2.6739 &= 472.0 \\
\text{antilog } 2.6730 &= 471.0 \\
\hline
\text{antilog } 2.6739 - \text{antilog } 2.6730 &= 1.0 \\
\frac{.6732 - .6730}{.6739 - .6730} &= 0.22 \\
0.22 \times 1.0 &= 0\ 22 \\
\text{antilog } 2.6730 &= 471.00 \\
\hline
\text{antilog } 2.6732 &= 471.22
\end{aligned}$$

2 Let 9 6321$-$10 be the logarithm of a number
   (a) The logarithm can he written $\bar{1}$ 6321, the negative characteristic indicating that the number is less than 1.
   (b) Since the characteristic is negative and has a numerical value of 1, the first significant figure of the number occupies the first place to the right of the decimal point.
   (c) The mantissa 0 6321 lies between the mantissas 0 6314 and 0 6325, being 7$-$11 or 0 636 times (0 6325$-$0 6314) greater than 0 6314.

(d) The antilogarithm of 9 6321−10 is therefore antilog (9 6321−10)+0 636 [antilog (9 6325−10)−antilog (9 6314 −10] or 0 42864 The procedure is as follows

$$
\begin{aligned}
\text{antilog } (9\ 6325 - 10) &= 0\ 429 \\
\text{antilog } (9\ 6314 - 10) &= \underline{0\ 428} \\
\text{antilog } (9\ 6325 - 10) - \text{antilog } (9\ 6314 - 10) &= 0\ 001 \\
\frac{0\ 6321 - 0\ 6314}{0\ 6325 - 0\ 6314} &= 0\ 636 \\
0\ 636 \times 0\ 001 &= 0\ 00064 \\
\text{antilog } (9\ 6314 - 10) &= \underline{0\ 42800} \\
\text{antilog } (9\ 6321 - 10) &= 0\ 42864
\end{aligned}
$$

Solution of an Exponential Equation

The relation between the intensity of transmitted and incident entering radiation is $I = I_0 e^{-\alpha t}$, in which I is intensity of trans mitted radiation, I_0 of the incident entering radiation, e the constant 2 7183, t the thickness of the absorbing material in cm, and α the absorption coefficient If $I = 80$, $I_0 = 100$, and $t = 1$ cm, what is α?

$$80 = 100e^{-\alpha \times 1}$$

Taking logarithms to the base 10 of this equation, we obtain

$$\log 80 = \log 100 - \alpha \log e$$

$$1\ 9031 = 2\ 0000 - 0\ 4343\alpha$$

whence $$\alpha = \frac{2\ 0000 - 1\ 9031}{0\ 4343} = 0\ 223$$

Table of Logarithms

A table of four place logarithms to the base 10 is given, which contains the mantissas of the logarithms of all numbers under 1000, the decimal point and characteristic being omitted The logarithms of single digits 1, 4, 5, etc, will be found at 10, 40, 50, etc Tables of more places are available, but this table will serve for many practical purposes Tables of a greater number of places should be used when a high degree of accuracy is required Such tables are used in the same manner as a four place table

In working with a four place table, the numbers corresponding to the logarithms, *i e* the antilogarithms, may be carried to four significant digits, with a six place table to six with a ten place table to ten, etc

N	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0178	0170	0212	0253	0294	0334	0374
11	0414	0433	0492	0531	0569	0607	0643	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1039	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1353	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2093	2122	2148	2173	2201	2227	2253	2279
17	2304	2330	2353	2380	2405	2430	2455	2480	2504	2529
18	2533	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	5284	5304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	5711	3729	3747	3766	3784
24	3802	5870	3838	3836	3874	5892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4423	4440	4436
28	4472	4487	4302	4318	4533	4348	4564	4579	4594	4609
29	4674	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
51	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5031	5063	5079	5092	5105	5119	5137	3145	3139	5172
53	5185	5198	5211	5224	5237	5230	5263	5276	3289	5302
54	5351	5328	5340	5353	5366	5338	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5577	3539	5351
36	5563	3575	5587	5599	5611	5623	5635	3647	5658	5670
37	5682	5694	5703	5717	5729	5740	5732	3763	3775	5786
38	5798	3809	5821	5832	5845	5855	5866	3877	3888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	3999	6010
40	6021	6031	6042	6053	6064	6075	6085	8096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6245	6253	6263	6274	6284	6294	6304	6514	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6434	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6655	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6995	7007	7016	7028	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7132
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7239	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396

N	0	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	[illegible]
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

APPENDIX B

TRIGONOMETRIC FUNCTIONS OF AN ANGLE

Definition of an Angle:

If a straight line is revolved about a perpendicular axis through one of its extremities, the line is said to generate an angle. If it is revolved in a counterclockwise direction, the generated angle is considered positive; in a clockwise direction, negative The initial position of the generating line is called the initial side, and the final position the terminal side of the angle. In reading an angle, the letter on the initial side is read first, then the letter designating the axis of rotation, and finally the letter on the terminal side For example, the angle generated by the clockwise rotation of a straight line from position OX to position OP in *Figure a*, is read *angle XOP*, or $\angle XOP$ If the angle is read in the opposite direction, the negative of the angle is meant.

Measure of an Angle:

Angles are measured in degrees or in radians

A *degree* is 1/360 of the plane angle about a point

A *radian* is the angle at the center of a circle which is subtended by an arc equal in length to the radius of the circle

Quadrants:

It is convenient to divide the plane of rotation of the generating line into four parts by the two mutually perpendicular lines XX' and YY', *Figure a* These parts are called the *first, second, third,* and *fourth quadrants*. The Roman numerals in *Figure a* designate the quadrants.

If OX is considered the initial side of an angle, the angle is said to lie in the quadrant in which its terminal side lies Positive angles of 0 to 90° lie in quadrant I; 90 to 180°, in quadrant II, 180 to 270°, in quadrant III; and 270 to 360°, in quadrant IV Angles greater than 360° or any integral multiple thereof, will lie in the first, second, third, or fourth quadrant depending upon how much greater than 360° or any integral multiple thereof the angle is For

example: angles of 375°, 760°, and 1100° lie in quadrant I; angles of 455°, 820°, and 1180° lie in quadrant II; etc

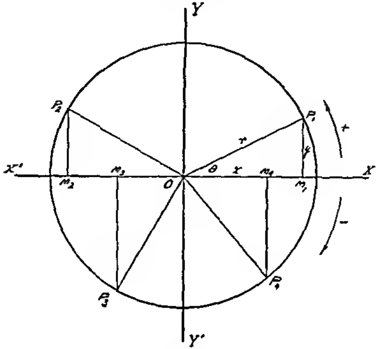

FIGURE a

Negative angles are generated by a clockwise rotation. Hence, negative angles of 0 to 90° lie in quadrant IV; 90 to 180°, in quadrant III; 180 to 270° in quadrant II; and 270 to 360°, in quadrant I. The quadrants in which negative angles greater than 360° lie are found as for positive angles.

Trigonometric Functions of an Angle:

Associated with any angle are six ratios of fundamental importance, upon which the whole subject of trigonometry is founded These ratios are called the *trigonometric functions of the angle.*

In *Figure a* four angles are shown, one in each quadrant. Points P_1, P_2, P_3, and P_4 are the points in which the terminal sides of the angles intersect the circle of radius r, which has the intersection of the two mutually perpendicular axes, XX' and YY', as a center.

Let M_1 M_2 M_3 and M_4 be respectively the points of intersection of perpendiculars from P_1 P_2 P_3 and P_4 and the axis XX

The trigonometric functions are defined as follows

$$\text{Sine of the angle} \quad \theta = \sin\theta = \frac{PM}{r} = \frac{y}{r}$$

$$\text{Cosine of the angle} \quad \theta = \cos\theta = \frac{OM}{r} = \frac{x}{r}$$

$$\text{Tangent of the angle} \quad \theta = \tan\theta = \frac{PM}{OM} = \frac{y}{x}$$

$$\text{Cotangent of the angle} \quad \theta = \cot\theta = \frac{OM}{PM} = \frac{x}{y}$$

$$\text{Secant of the angle} \quad \theta = \sec\theta = \frac{r}{OM} = \frac{r}{x}$$

$$\text{Cosecant of the angle} \quad \theta = \operatorname{cse}\theta = \frac{r}{PM} = \frac{r}{y}$$

From the above it is seen that

$$\cot\theta = \frac{1}{\tan\theta}$$

$$\sec\theta = \frac{1}{\cos\theta}$$

$$\operatorname{cse}\theta = \frac{1}{\sin\theta}$$

Hence, knowing the values of the sine cosine and the tangent of an angle the reciprocal functions can be readily computed

SIGNS OF THE FUNCTIONS OF ANGLES IN VARIOUS QUADRANTS

Function	I	II	III	IV
Sine	+	+	−	−
Cosine	+	−	−	+
Tangent	+	−	+	−

FUNCTIONS OF COMMON ANGLES

	0°	30°	45°	60°	90°	180°	270°	360°
Sin	0	1/2	$1/2\sqrt{2}$	$1/2\sqrt{3}$	1	0	−1	0
Cos	1	$1/2\sqrt{3}$	$1/2\sqrt{2}$	1/2	0	−1	0	1
Tan	0	$1/3\sqrt{3}$	1	$\sqrt{3}$	∞	0	∞	0

FUNCTIONS OF ANGLES IN ANY QUADRANT IN TERMS OF ANGLES IN FIRST QUADRANT

	$-\theta$	$90° \pm \theta$	$180° \pm \theta$	$270° \pm \theta$	$n(360)° \pm \theta$
Sin	$-\sin\theta$	$+\cos\theta$	$\mp\sin\theta$	$-\cos\theta$	$\pm\sin\theta$
Cos	$+\cos\theta$	$\mp\sin\theta$	$-\cos\theta$	$\pm\sin\theta$	$+\cos\theta$
Tan	$-\tan\theta$	$\mp\cot\theta$	$\pm\tan\theta$	$\mp\cot\theta$	$\pm\tan\theta$

Finding the Trigonometric Functions of an Angle

1. Let the angle be 33° 14′. Find (a) its sine, (b) its cosine, (c) its tangent.

(a) From *Table of Trigonometric Functions,*

$$\begin{aligned}
\sin 34° &= 0.5592 \\
\sin 33 &= \underline{0.5446} \\
\text{Difference} &= 0.0146
\end{aligned}$$

$$\frac{33°\,14' - 33°}{34° \quad - 33°} = \frac{14}{60} = 0.233$$

$$\begin{aligned}
0.233 \times 0.0146 &= 0.0034 \\
\sin 33° &= \underline{0.5446} \\
\sin 33°\,14' &= 0.5480
\end{aligned}$$

(b)

$$\begin{aligned}
\cos 33 &= 0.8387 \\
\cos 34 &= \underline{0.8290} \\
\text{Difference} &= 0.0097
\end{aligned}$$

$$\frac{33°\,14' - 33°}{34° - 33°} = 0.233$$

$$\begin{aligned}
0.233 \times 0.0097 &= 0.0023 \\
\cos 33° &= 0.8387
\end{aligned}$$

$$\cos 33°\,14' = \cos 33° - 0.0023 = 0.8364$$

(c)
$$\begin{array}{ll}
\tan 34^\circ & = 0.6745 \\
\tan 33^\circ & = \underline{0.6494} \\
\quad \text{Difference} & = 0.0251 \\
\dfrac{33^\circ\,14' - 33^\circ}{34^\circ - 33^\circ} & = 0.233 \\
0.233 \times 0.0251 & = 0.0058 \\
\tan 33^\circ & = \underline{0.6494} \\
\tan 33^\circ\,14' & = 0.6552
\end{array}$$

2 Let the angle be 138° 20′. Find its sine, cosine, and tangent.

The angle 138° 20′ is in the second quadrant; therefore, its sine is positive, its cosine negative, and its tangent negative. Numerically its functions are those of its supplementary angle, or that angle which with it makes an angle of 180°. Hence,

$$\begin{array}{l}
\text{Sin } 138^\circ\,20' = \sin\,(180^\circ - 138^\circ\,20') = \sin 41^\circ\,40' = 0.6648 \\
\text{Cos } 138^\circ\,20' = -\cos\,(180^\circ - 138^\circ\,20') = -\cos 41^\circ\,40' = -0.7470 \\
\text{Tan } 138^\circ\,20' = -\tan\,(180^\circ - 138^\circ\,20') = -\tan 41^\circ\,40' = -0.8899
\end{array}$$

3 Let the angle be 714°. Find its functions

The angle of 714° is generated by rotating the generating line counterclockwise one complete revolution and (714 − 360)/360 of a second. The angle lies in the fourth quadrant and hence its sine is negative, its cosine positive, and its tangent negative Numerically its functions are those of the angle of 720° − 714° or 6° Hence

$$\begin{array}{llll}
\sin 714^\circ = & -\sin 6^\circ & = & -0.1045 \\
\cos 714^\circ = & \cos 6^\circ & = & 0.9945 \\
\tan 714^\circ = & -\tan 6^\circ & = & -0.1051
\end{array}$$

4. Let the angle be −75° 17′. Find its functions.

The angle of −75° 17′ is generated by rotating the radius vector clockwise until it makes an angle of 75° 17′ with the line representing its initial position. The angle is obviously in the fourth quadrant, and hence its sine is negative, its cosine positive, and its tangent negative. Numerically its functions are equal to the corresponding functions of a positive angle of 75° 17′. Since the co-functions of complementary angles are equal, we may write

$$\begin{array}{llllll}
\sin -75^\circ\,17' = & -\sin 75^\circ\,17' = & -\cos 14^\circ\,43' = & -0.2540 \\
\cos -75^\circ\,17' = & \cos 75^\circ\,17' = & \sin 14^\circ\,43' = & 0.9672 \\
\tan -75^\circ\,17' = & -\tan 75^\circ\,17' = & -\cot 14^\circ\,43' = & -3.807
\end{array}$$

Finding the Angle or Angles Corresponding to a Given Trigonometric Function

1. Let the sine of an angle be 0.4136. Find the angle.

The angle whose sine is a given value, such as 0.4136, is referred to as the *arcsine 0.4136*, abbreviated *arcsin 0.4136*. From the *Table of Trigonometric Functions*, it is found that the angle desired lies between *24°*, whose sine is *0.4067*, and *25°*, whose sine is 0.4226. The procedure to be followed is

$$\begin{aligned}
&\arcsin 0.4226 &&= 25^\circ \\
&\arcsin 0.4067 &&= \underline{24^\circ} \\
&\arcsin 0.4226 - \arcsin 0.4067 &&= 1^\circ \\
&\frac{0.4136 - 0.4067}{0.4226 - 0.4067} &&= 0.43+ \\
&0.43 \times 1^\circ &&= 0.43^\circ \\
&\arcsin 0.4067 &&= 24.00^\circ \\
\arcsin 0.4136 = {}&\arcsin 0.4067 + 0.43^\circ &&= 24.43^\circ
\end{aligned}$$

2. Let the cosine of an angle be 0.8642. Find the angle.

Proceeding as in Example 1

$$\begin{aligned}
&\arccos 0.8572 &&= 31^\circ \\
&\arccos 0.8660 &&= \underline{30^\circ} \\
&\arccos 0.8572 - \arccos 0.8660 &&= 1^\circ \\
&\frac{0.8642 - 0.8572}{0.8660 - 0.8572} &&= 0.8+ \\
&0.8 \times 1^\circ &&= 0.8^\circ \\
&\arccos 0.8572 &&= \underline{31^\circ} \\
&\arccos 0.8642 &&= 30.2^\circ
\end{aligned}$$

3. Let the tangent of an angle be 1.6542. Find the angle.

Proceeding as in foregoing examples

$$\begin{aligned}
&\arctan 1.6643 &&= 59^\circ \\
&\arctan 1.6003 &&= \underline{58^\circ} \\
&\arctan 1.6643 - \arctan 1.6003 &&= 1^\circ \\
&\frac{1.6542 - 1.6003}{1.6643 - 1.6003} &&= 0.84+ \\
&0.84 \times 1^\circ &&= 0.84^\circ \\
&\arctan 1.6003 &&= \underline{58.00^\circ} \\
&\arctan 1.6542 &&= 58.84^\circ
\end{aligned}$$

Trigonometric Functions

Angle	Sine	Cosine	Tangent	Angle	Sine	Cosine	Tangent
0°	0 000	1 000	0 000	45°	0 707	0 707	1 000
1	017	1 000	017	46	719	695	1 036
2	035	0 999	035	47	731	682	1 072
3	052	999	052	48	743	669	1 111
4	070	998	070	49	755	656	1 150
5	0 087	0 996	0 087	50	0 766	0 643	1 192
6	105	995	105	51	777	629	1 235
7	122	993	123	52	788	616	1 280
8	139	990	140	53	799	602	1 327
9	156	988	158	54	809	588	1 376
10	0 174	0 985	0 176	55	0 819	0 574	1 428
11	191	982	194	56	829	559	1 483
12	208	978	213	57	839	545	1 540
13	225	974	231	58	848	530	1 600
14	242	970	249	59	857	515	1 664
15	0 259	0 966	0 268	60	0 866	0 500	1 732
16	276	961	287	61	875	485	1 804
17	292	956	306	62	883	469	1 881
18	309	951	325	63	891	454	1 963
19	326	946	344	64	899	438	2 050
20	0 342	0 940	0 364	65	0 906	0 423	2 145
21	358	934	384	66	914	407	2 246
22	375	927	404	67	921	391	2 356
23	391	921	424	68	927	375	2 475
24	407	914	445	69	934	358	2 605
25	0 423	0 906	0 466	70	0 940	0 342	2 747
26	438	899	488	71	946	326	2 904
27	454	891	510	72	951	309	3 078
28	469	883	532	73	956	292	3 271
29	485	875	554	74	961	276	3 487
30	0 500	0 866	0 577	75	0 966	0 259	3 732
31	515	857	601	76	970	242	4 011
32	530	848	625	77	974	225	4 331
33	545	839	649	78	978	208	4 705
34	559	829	675	79	982	191	5 145
35	0 574	0 819	0 700	80	0 985	0 174	5 671
36	588	809	727	81	988	156	6 314
37	602	799	754	82	990	139	7 115
38	616	788	781	83	993	122	8 144
39	629	777	810	84	995	105	9 514
40	0 643	0 766	0 839	85	0 996	0 087	11 43
41	656	755	869	86	998	070	14 30
42	669	743	900	87	999	052	19 08
43	682	731	933	88	999	035	28 64
44	695	719	966	89	1 000	017	57 29
45°	0 707	0 707	1 00	90°	1 000	0 000	∞

INDEX

A

B

C

E

G

H

I

J

L

M

N

O

Q

R

S

T

THIS BOOK

TECHNIC of ELECTROTHERAPY *and* ITS PHYSICAL *and* PHYSIOLOGICAL BASIS

SECOND PRINTING

By

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other rare earth type of elements in addition to carbon, the *Therapeutic C Carbon* contains iron, aluminum, and nickel in addition to carbon and the *Therapeutic E Carbon* contains strontium The so called *Sunshine* carbon was designed to produce radiation of the type that is present in sunshine, the *Therapeutic C* carbon to produce a maximum amount of radiation in the spectral zone, 2000 A U to 3200 A U and the *Therapeutic E* carbon to produce maximum amounts of radiation in the zone 7000 A U to 10,000 A U the zone of penetrating thermogenic radiation

The *Sunshine* carbon arc lamp is used as a sun lamp in an endeavor to provide solar type of radiation to indoor workers of urban communities during those months that sunshine contains but a negligible amount of biologically important radiation of wavelength less than 3200 A U The *Therapeutic C* carbon arc is used for the production of therapeutic intensities of radiation in the zone 2000 A U to 3200 A U The *Therapeutic E* carboo arc is used where heat is particularly indicated, the relatively low output of rays of 3200 A U to 2000 A U making possible the relatively long exposures required for obtaining the desired thermogenic effect of the radiation in the zone 7000 A U to 10 000 A U An example of the proper use of such a lamp would be in the treatment of such conditions as arthritis

The carbon arc lamp equipped with *Sunshine* carbons is frequently referred to as an artificial source having a qualitative radiation output that most nearly approaches natural sunlight, but a comparison of the spectral distribution curve of this arc as well as those of the 'C' carbon arc and the "E" carbon arc, Fig 79, with the spectral energy distribution curve of the sun, Fig 78 will convince one of the vast difference existing between the radiation from the sun and that from such carbon arcs All carbon arcs emit the characteristic radiation of carbon, as well as that of the metals with which the carbon electrode may be impregnated Such characteristic radiation lies in the near ultra violet zone from approximately 3500 A U to 4000 A U, a zone which has not been established as having any desired therapeutic effects This band of radiation, due to carbon, is known as the *Cyanogen* band

b. *Mercury Vapor Arcs* A highly efficient and widely used source of ultraviolet radiation is the mercury vapor arc. The mercury must of course be confined within a tube or burner, either of fused quartz or other material, having a high transmission for ultraviolet radiation of therapeutic value. The radiation from this arc, maintained in the mercury vapor under relatively high pressure as compared with the pressure of the glow type of mercury vapor lamp, is the characteristic mercury spectrum under such conditions of operation It consists of a series of strong emission lines with a relatively high percentage of its radiation output in the zone of interest to those employing ultraviolet radiation for therapeutic purposes, namely, the zone 2000 A.U. to 3200 A U.

(1) *Fused-Quartz Mercury Arc Lamp.* The mercury arc in a fused quartz envelope, with a liquid mercury cathode, is well known to the medical profession Most of such lamps are necessarily direct current devices Recently, alternating current fused-quartz mercury arc lamps have been developed, of which there are two types: one utilizing two oxide-coated tungsten cathodes; and the other, three pure tungsten electrodes, one of them a starting electrode Both lamps combine high efficiency, long life, stability, and reliability of operation. The new lamps are essentially straight lengths of fused-quartz tubing, approximately ¾ inch in diameter and 6 inches long, containing a carefully measured quantity of mercury and small amounts of rare gases to initiate the discharge

These new lamps have a definite advantage over the older liquid-mercury cathode type. In using the older lamp, it is necessary to tilt the lamp to initiate the discharge, and it could be operated only in a specified position, or burning angle. The new lamps are automatic in starting, and can be burned horizontally, vertically, or at any desired angle. In about 3 to 4 minutes after starting, when all the mercury is in the vapor form, the final and stable operating condition is reached. After stabilization, the mercury is completely vaporized at a pressure of ½ to 1 atmosphere. The voltage across the arc remains stable from this point on.

In the case of the lamp with oxide coated electrodes, the emis-